

Moon Chronicle

Part 3

Zond 4 to Apollo 12

by

Phil Stooke

Luna 13

PROCELLARUM

Luna 8

Luna 9

Luna 7

Lunar Orbiter 4

Surveyor 1

Surveyor 3 - Apollo 12

Luna

MARE
HUMORUM

Moon Chronicle

Part 3: Zond 4 to Apollo 12

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Introduction

Ranger, Surveyor and Lunar Orbiter had provided the data necessary to plan for the Apollo landing missions. All attention was now directed to landing site selection and the two rehearsal flights which would precede the first landing. This section of the Moon Chronicle covers the first four Apollo flights to the Moon, the rehearsal flights of Apollo 8 and Apollo 10, the historic first landing by Apollo 11 and the second landing by Apollo 12. It also looks ahead to later Apollo landings and early thoughts about future exploration possibilities.

Meanwhile the Soviet Union was working to catch up, having lost its lead in the early years of the 'Space Race'. Its main accomplishments at the Moon in this period were the lunar swingby and return flights of the lunar crew capsule test articles Zond 4 to Zond 7 (Zond 8 is covered in the next volume of the Moon Chronicle). They provided some photography of the Moon but were not yet ready for crewed flights. These Zonds eventually evolved into the Soyuz capsules used over the following decades for space station missions.

Latitude and longitude coordinates in tables and on maps are taken from the original source documents and are presented as decimal degrees or degrees, minutes and seconds without any conversion. Where coordinates of features have become more accurate in the past 50 years there will sometimes be small discrepancies between older and modern positions, and complete consistency has not been attempted.

Each volume of the Chronicle includes a map and table showing spacecraft landing or impact locations covered in that volume. In this case the list is very short, containing only Apollo 11 and 12 and Luna 15. They are presented in an appendix at the end of the volume.

Spacecraft image credits:

Lunar Reconnaissance Orbiter camera (LROC) data: NASA/GSFC/Arizona State University, and Robinson, M.S., *et. al.* (2010). Lunar Reconnaissance Orbiter Camera (LROC) Instrument Overview, *Space Science Reviews*, v. 150, pp. 81-124. <https://doi.org/10.1007/s11214-010-9634-2>

Lunar Reconnaissance Orbiter Laser Altimeter (LOLA): Smith, D.E., Zuber, M.T., Jackson, G.B. *et al.*, 2010. The Lunar Orbiter Laser Altimeter investigation on the Lunar Reconnaissance Orbiter mission. *Space Science Reviews*, v. 150, pp.209-241. <https://doi.org/10.1007/s11214-009-9512-y>

Lunar QuickMap (<https://quickmap.lroc.asu.edu>), developed by NASA, Arizona State University and Applied Coherent Technology Corp.

Luna: All Luna images, maps derived from them and any other material originating from the Soviet Union were provided courtesy of V. V. Shevchenko, Director, Sternberg State Astronomical Institute, Moscow and his colleagues. These materials were not copyrighted.

Zond: All Zond 6, 7 and 8 images and related materials were made available by Kira Shingareva and her colleagues at MIIGAiK, now the Moscow State University of Geodesy and Cartography (which still uses its older acronym).

Lunar Orbiter: NASA/JSC, Lunar and Planetary Institute (<https://www.lpi.usra.edu/resources/lunarorbiter/#support>), Lunar Orbiter Image Recovery Project: (<https://catalog.archives.gov/id/77811149>)

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07 February 1968: Luna 1968A

This Soviet spacecraft was intended to be a lunar orbiter, apparently similar to Luna 10 in structure but equipped to test navigation and communications procedures for the Soviet Union's lunar cosmonaut program. 525 seconds after launch the third stage engine shut down prematurely when it ran out of fuel. A seized valve or fuel inlet control may have been responsible. The upper stages and spacecraft broke up in the atmosphere.



12 March 1968: Zond 4

Zond 4 was the first deep space test, without a crew, of the Soyuz spacecraft intended to send cosmonauts to the Moon. It was launched from Baikonur at 18:29 UT into a parking orbit on a Tyazheliy Sputnik (Heavy Sputnik, an orbital launch platform), then injected into a 330 000 km apogee Earth orbit. This took it roughly to the distance of the Moon but 180° away from it, so there was no close approach to the Moon. The mission tested both spacecraft systems and the complex re-entry procedure, which involved an initial pass through the upper atmosphere to reduce speed before the final re-entry and landing on Soviet territory. The guidance system failed and the planned manoeuvre was not possible. To prevent the recovery of the vehicle by the United States, the spacecraft self-destruct system was activated 12 km above the Gulf of Guinea. Re-entry occurred 5.2 days after launch.

This and later spacecraft designated Zond were unrelated to the previous Zond 3. The 5140 kg capsule was cylindrical with one rounded end, 4.5 m long and up to 2.7 m in diameter, attached to a cylindrical instrument module carrying twin solar panels, folded at launch, which spanned nearly 9 m. The spacecraft carried a proton detector. Later Zonds carried cameras, but it is not known if Zond 4 did.



26 March 1968: Apollo Site Selection Board

At this meeting the Board looked at candidate sites for the second and third landings (Table 35). Site IP-1 (A-1 in Figure 53) was dropped from consideration for the second landing, and pinpoint landing targets for the second mission were identified (Figure 112). Four candidate sites for the third landing were presented (Figure 113). For future landings, a survey of Lunar Orbiter 5 images showed that of 36 sites photographed, ten were inadequately covered (no stereoscopic viewing for topographic mapping), four were marginal and 22 were satisfactory. Of those, ten were rejected based on the radar constraints on the approach, leaving twelve for future study.

The following site selection procedure for later missions was adopted. A set of about 80 sites, called Set A, would consist of all sites having high resolution imaging from Orbiters 2, 3 and 5. From them would be selected about 20 sites of higher scientific interest and accessible to Apollo at least one day per year (Set B). For any given mission a small Set C of specific targets would be chosen. The need for three sites per mission to accommodate launch delays was still assumed at this time, but efforts to reduce launch recycle times were in progress.

A brief assessment of some Santa Cruz sites was presented. The Alphonsus and Marius Hills sites seemed possible. Tycho and Schröter's Valley had bad approaches, and Hadley Rille had only marginal photographic data. Copernicus suffered from both marginal data and a bad approach.

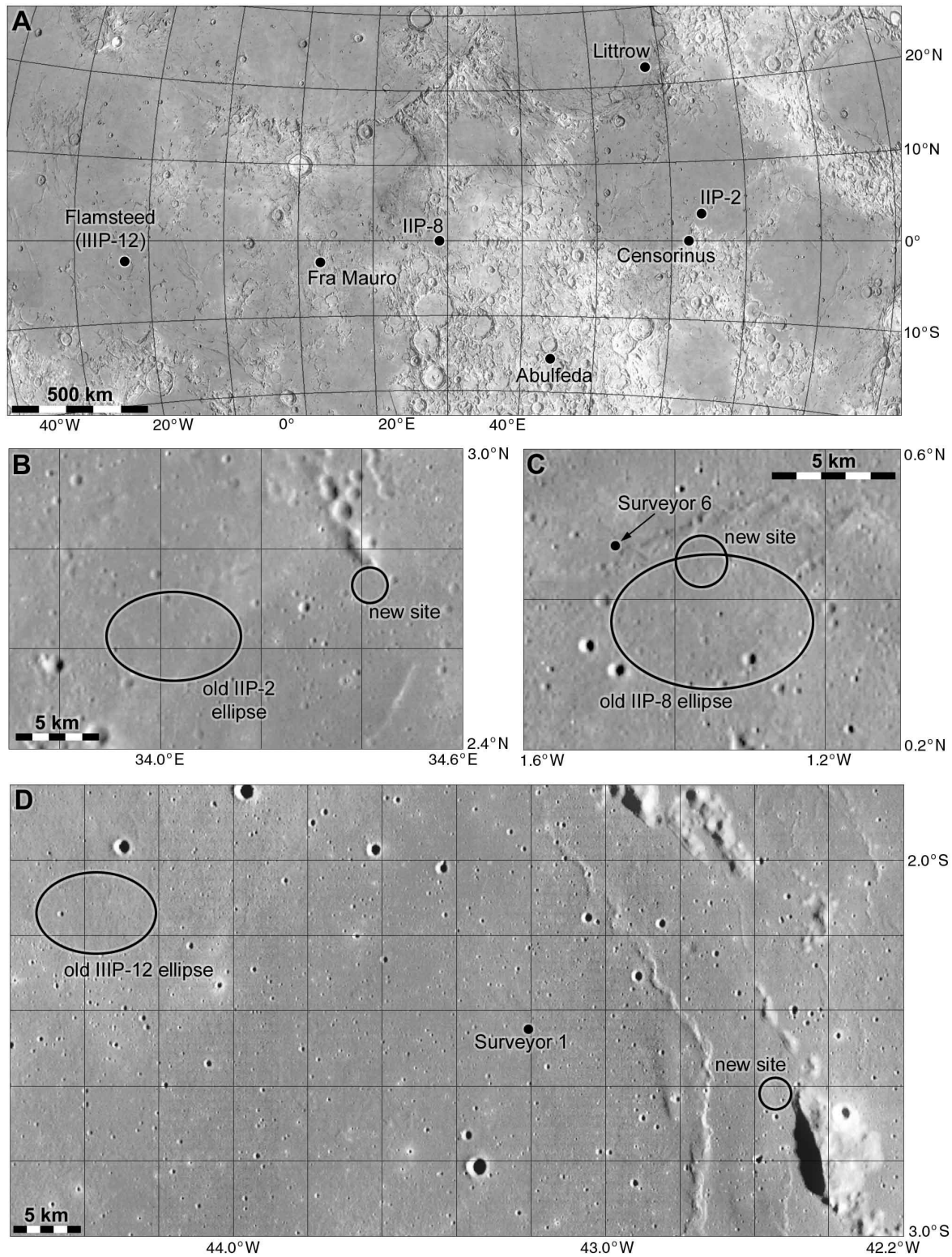


Figure 112. Apollo landing sites. A: sites for the second and third Apollo landings. B: redesignated site in Mare Tranquillitatis. C: redesignated site in Sinus Medii. D: redesignated site near Flamsteed. B, C and D images are LROC wide angle mosaics adjusted to match Apollo-era maps and are offset slightly from modern LRO coordinates.

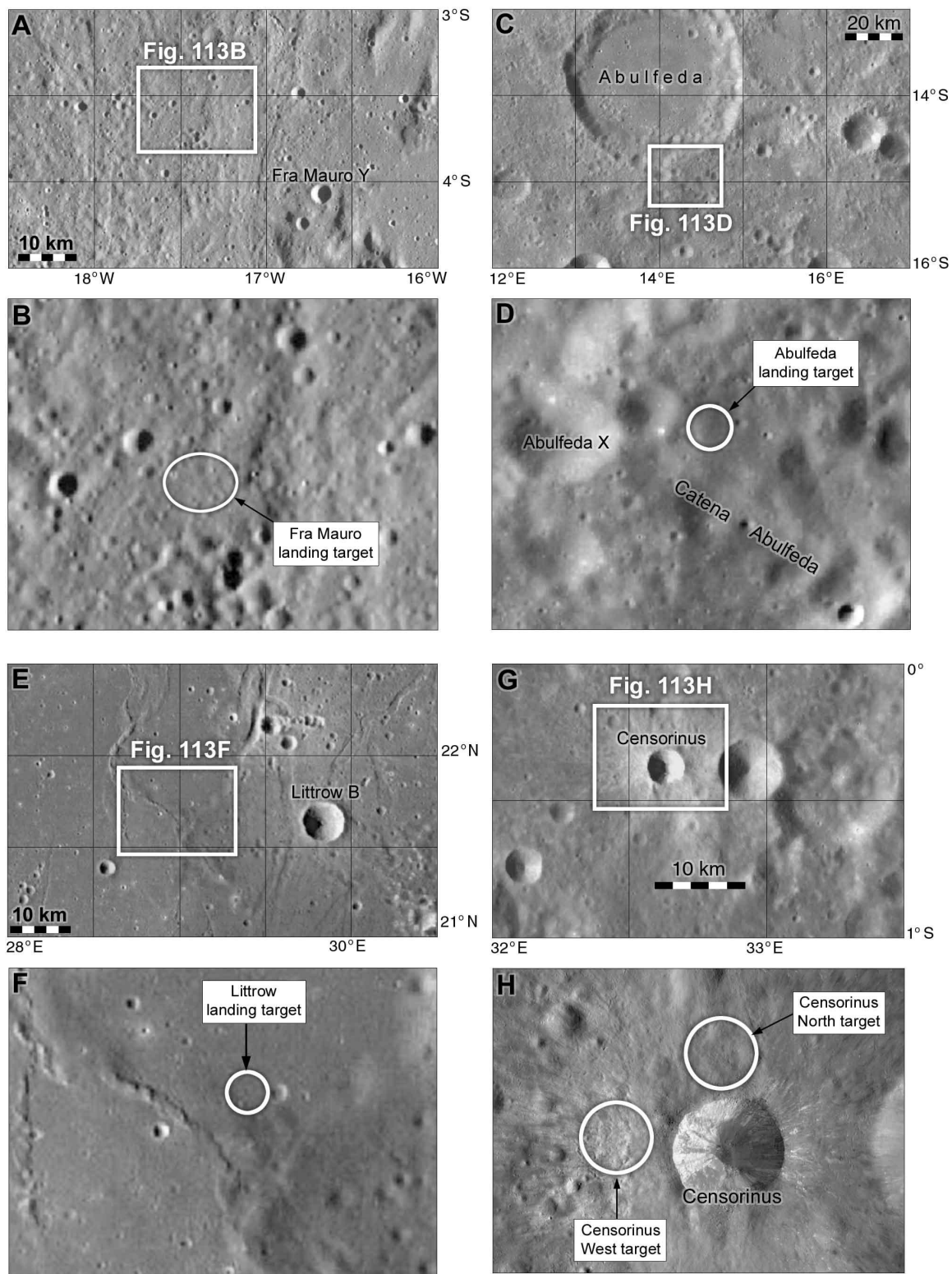


Figure 113. Apollo science sites. A, B: Fra Mauro. C, D: Abulfeda. E, F: Littrow. G, H: Censorinus. The images are LROC wide angle mosaics except for H which is a narrow angle mosaic. Gridded maps are fitted to the contemporary (1968) coordinates, not LRO coordinates.

Table 35. Candidate Apollo sites for landing missions 2 and 3			
category	Site characteristics or location	position	comments
Apollo Zone Redesignated Science Sites	Mare-terra contact in IIP-2	2° 43.5' N, 34° 24' E	acceptable
	Crater, ridge and mare ridge contact in IIP-8	0° 29' N, 1° 17' W	acceptable
	Flamsteed Ring in IIIP-12 (mare with hills of uncertain origin)	2° 37' S, 42° 32' W	Marginal data
Apollo Zone Science Sites	Censorinus north (very recent impact crater)	0° 17' S, 32° 39' E	unacceptable
	Censorinus West (very recent impact crater)	0° 23' S, 32° 32' E	unacceptable
	Fra Mauro (terra material)	3° 45' S, 17° 36' W	unacceptable
Science Sites Outside Apollo Zone	Abulfeda (chain craters, possible volcanic material)	14° 57' S, 14° 18' E	unacceptable
	Littrow (mare ridge, dark material)	21° 44' N, 29° 02' E	acceptable

Figure 112A shows seven sites now considered for the second and third landings. The IIP-2, IIP-8 and IIIP-12 targets were now 1 km radius circles rather than 5.3 by 7.9 km ellipses, on the assumption that operational experience would allow more precise landings after the first attempt. The circles were 'redesignated' sites chosen to place scientifically interesting features within walking distance of the landed spacecraft, hills at IIP-2 (Figure 112B) and IIIP-12 (112D), and a mare ridge at IIP-8 (112C). Two of the sites were close to landed Surveyor spacecraft, but there was no plan at this time to visit the Surveyor itself.

Figure 113 illustrates the science sites considered for the third Apollo landing, Fra Mauro, Abulfeda, Littrow and Censorinus. The ellipse at Fra Mauro, on the massive ejecta deposit of the Imbrium basin, was to become the Apollo 14 landing site. The crater chain Catena Abulfeda was thought at the time to be a chain of volcanic vents. Now it would probably be interpreted as of impact origin. Littrow, about 75 km northwest of the Apollo 17 landing site, was on a dark deposit of pyroclastic material. Censorinus was a highland site with a very young impact crater, and two possible landing locations were being evaluated.



07 April 1968: Luna 14

This Soviet lunar orbiter made measurements similar to those of Luna 10 including lunar gravity, solar charged particles and cosmic rays, though few details are available. Lunokhod motors and/or gear lubricants may have been tested, as on Luna 12. It is now known that the main function of Luna 14 was to test tracking and communications systems for the Soviet manned lunar program. Launch was at 10:09 UT from Baikonur, and a trajectory correction was made at 19:27 UT on 8 April. The 1700 kg Luna 14 spacecraft entered a 150 by 870 km, 160 minute lunar orbit inclined 42° to the equator on 10 April, and operated until its final transmission on 4 July 1968. This was the final mission in the second generation (orbiter and lander) series of Luna spacecraft. Luna 14 probably struck the Moon as its orbit evolved, at an unknown location.

According to Zelenyi *et al.* (2011) Luna 14 was preceded by a similar mission, Kosmos 159, which operated in a highly elliptical Earth orbit after launch on 17 May 1967. It was said to be an upgraded version of Luna 12 which would map lunar gravity and test communications for future human missions, but it was stranded in a 350 by 60,637 km Earth orbit after a launch vehicle fault. Though represented as intended for a higher Earth orbit, the gravity mapping would be impossible outside a lunar orbit, so that was probably intended.

Zelenyi, L. M., Zakharov, A. V. and Zakutnyaya, O. V., 2011. *Will the Lunar Renaissance Come Forth?* Solar System Research, v. 45, no. 7, pp. 697–704. <https://doi.org/10.1134/S003809461107029X>



1968: Apollo Site Screening

The Mapping Sciences Branch at MSC in Houston examined all Lunar Orbiter high resolution images to identify the Set A potential sites for later Apollo landings. In all, 57 sites photographed by Orbiters 2, 3 and 5 were considered (Surface Analysis Group, 1968). The screening procedure was similar to that for earlier sites except that a smaller landing target, a 1.5 km radius circle, was used. The landing target was 1 km in radius, and the astronaut walking range was taken to be 1.5 km, so the circles shown in Figures 114-119 are 3 km in diameter. The black circles were the preferred sites, and white circles are less satisfactory locations. Lines extending eastwards from each black circle show the range of approach directions which had to be reasonably free of obstacles. Of 148 targets screened, 88 were thought suitable for further study.

All Lunar Orbiter sites screened at this time by MSC for Apollo exploration landing sites are illustrated in Figures 114-119, with a map of their locations in Figure 119. Most of these sites are equatorial, reflecting the nature of Lunar Orbiter photography targeting. The sites are numbered in Figures 90, 105 and 126 and Table 30, for comparison with Figure 162. Note that Site IIS-16 (Figure 115) was (correctly) called IIS-11 on Figure 70. This was a mistake in the MSC report. Points marked 'X' in Figures 114-119 are sites from other documents of this period and are from Table 36.

The images in Figures 114-119 have been modified cosmetically after being reproduced directly from the report, but the image quality reflects that of the original material. The first two sites in Figure 119, taken from Addendum II of the report, were highland sites in the Apollo zone that were considered suitable for an early landing. The three potential targets (black circles shown on those two sites) were ranked in order of landability as follows: (1 - best) Site IIS-15-1, 0° 27' N, 5° 50' W; (2) Site IIS-10-1, 1° 18' S, 13° 31' E; (3) Site IIS-10-2, 1° 43' S, 13° 24' E.

Another iteration of this selection process is recorded in an unattributed document in the branch history collection at USGS Flagstaff, produced in June 1968 by the GLEP site selection subgroup, the 'rump GLEP' (Wilhelms 1993). The report identified 17 'AAP landing sites' in Lunar Orbiter 5 imaging sites, two of them in Copernicus (Table 36a). In Figures 114-119 these are identified with an 'X' and labelled GLEP. At Fra Mauro (Site V-34) the GLEP site corresponds with MSC site 4. Two sites very different from MSC choices, Littrow and Alexander, are illustrated as the last two sites in Figure 119. For context, the Littrow site is on the upper right edge of Figure 113E. The Alexander area is also shown in Figure 104A.

Bellcomm also considered potential sites for later missions, as described by Silberstein (1968) and El-Baz (1968). Their nine sites (from Silberstein) are listed in Table 36b. Multiple landing points were suggested at Copernicus, Hadley, Schröter's Valley and Marius Hills. Some of these differ from MSC sites. Many of them are indicated with an 'X' and labelled B (for Bellcomm) in Figures 114-119. The remaining site at Abulfeda and some alternative sites at Marius Hills, Tobias Mayer and Littrow are illustrated in Figure 120.

The Censorinus and Littrow sites are the same as those in Figure 160. The Hadley site is the same as MSC's site 2 (Figure 127). The Tycho site is at Surveyor 7, whereas MSC's was not (Figure 125). One Copernicus site in a melt pond on a wall terrace was the same as MSC's site 1 (Figure 125). At Abulfeda (Figure 120D) the site differs from Figure 113. El-Baz noted that a walking mission could be conducted north of the crater chain, but a lunar flying unit (LFU) would be desirable to reach supposed volcanic hills inside one of the vent craters. At Marius, Silberstein identified three sites by coordinates, marked with a 'B' (Bellcomm) in Figure 120A. The Silberstein and El-Baz documents differ slightly, El-Baz adding additional landing points at both Hadley and Copernicus. Additional sites at Tobias Mayer and Littrow are illustrated in Figure 120, taken from miscellaneous material in the USGS Flagstaff branch history collection. The multiple versions of these site suggestions illustrate the complex and hurried nature of site planning at this time.

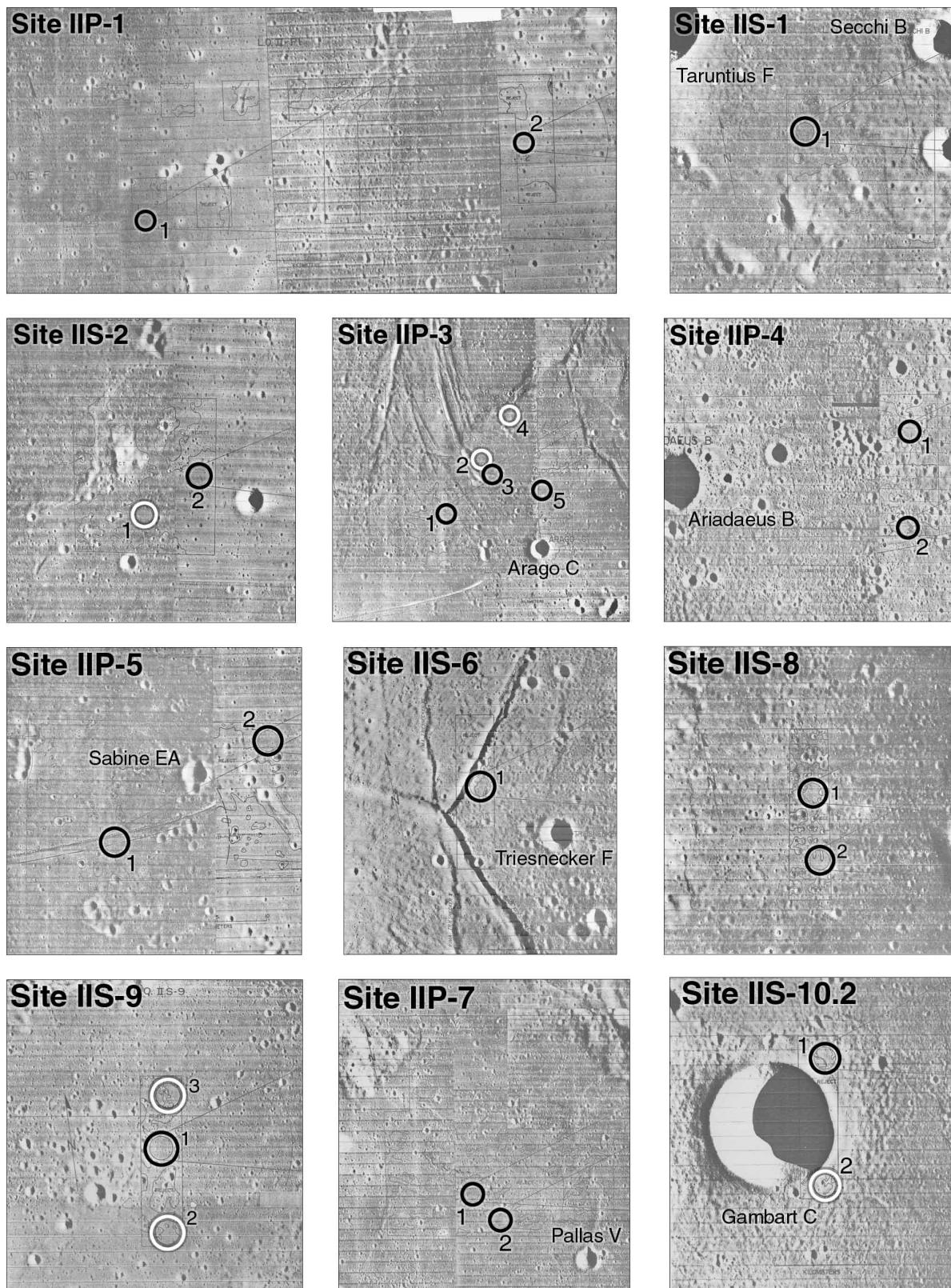


Figure 114: Set A potential sites for later Apollo landings (Surface Analysis Group, 1968). For scale, circles are 3 km across. Black circles are preferred locations.

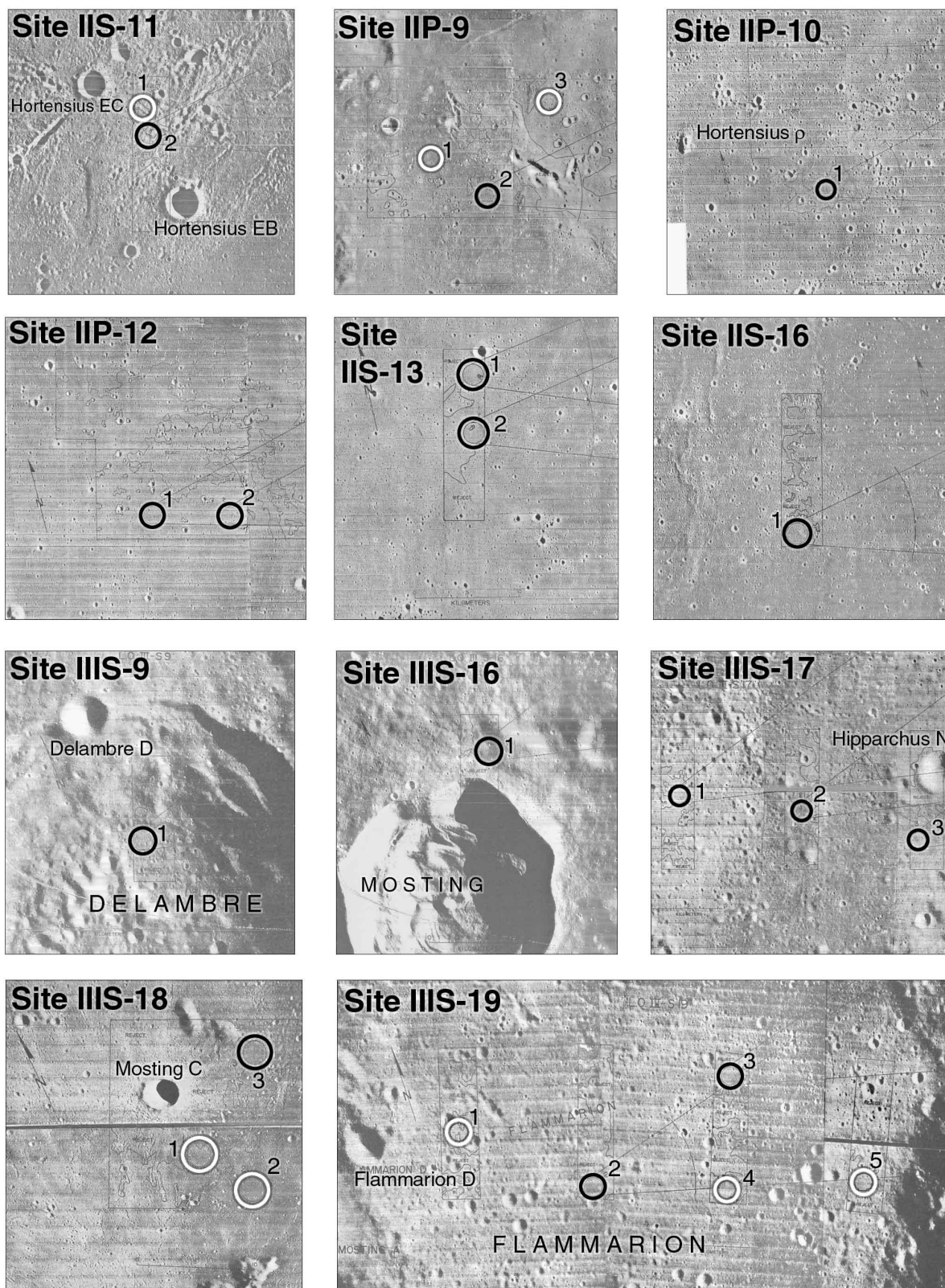


Figure 115. Set A potential sites, continued from Figure 114. Site IIS-16 should be called IIS-11 (a mistake in the source).

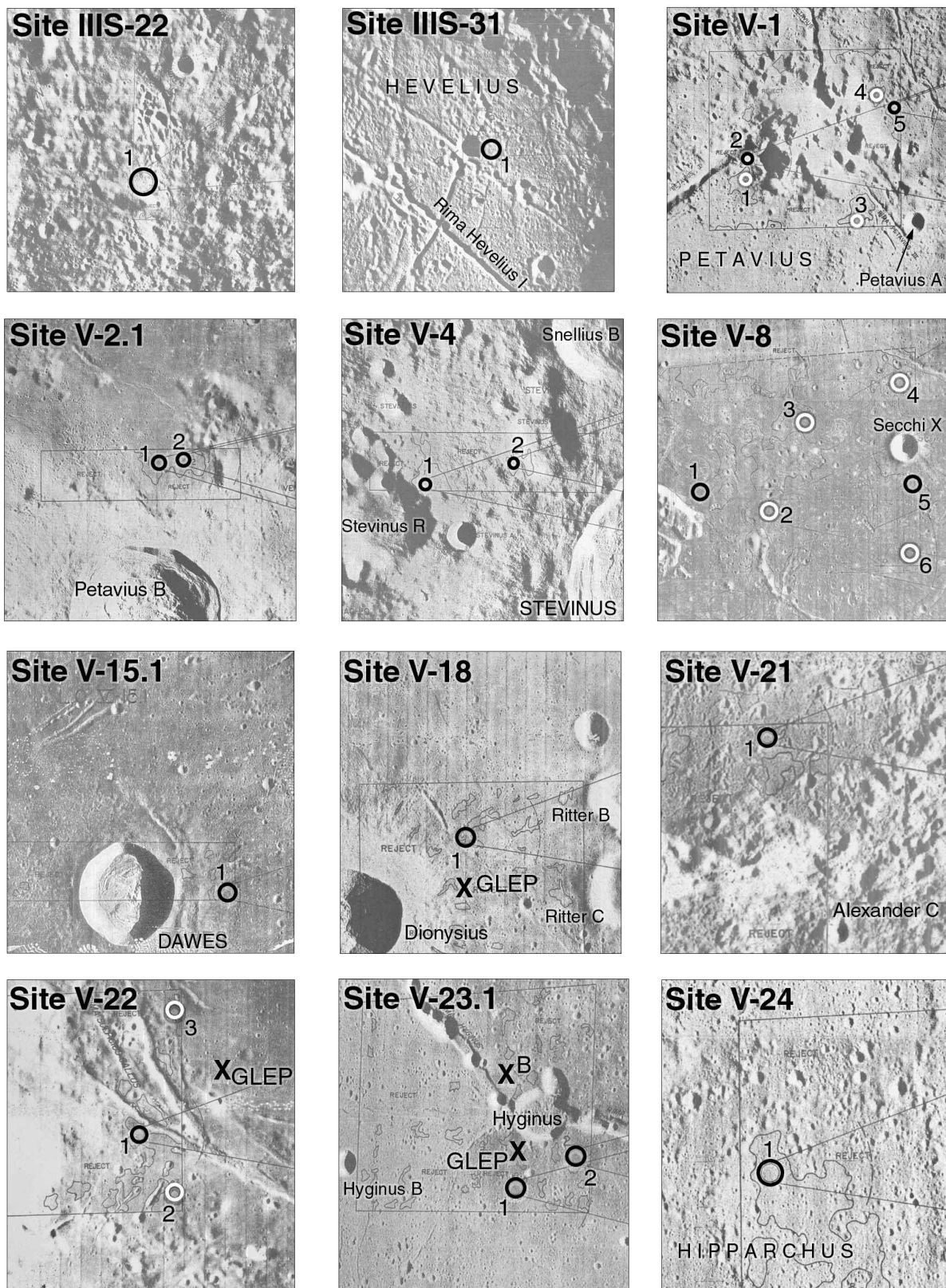


Figure 116. Set A potential sites, continued from Figure 115. Sites shown with **X** are from Table 36 and are labelled GLEP or B (for Bellcomm) to indicate the source.

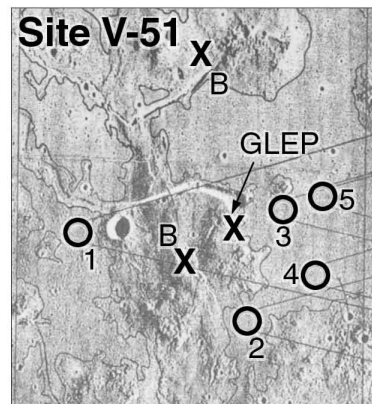
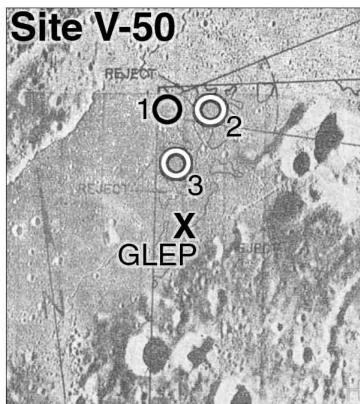
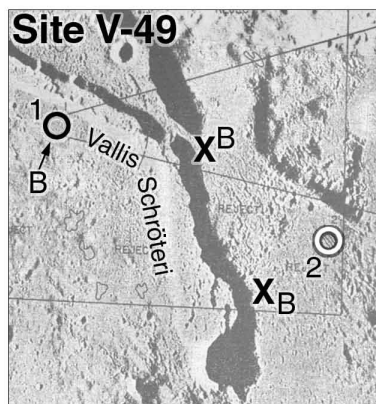
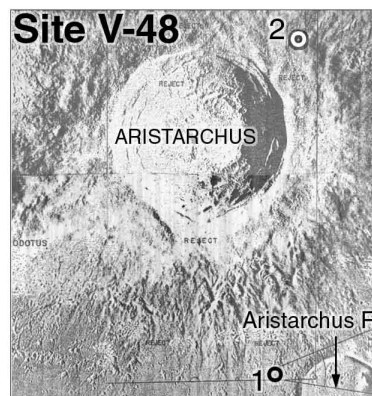
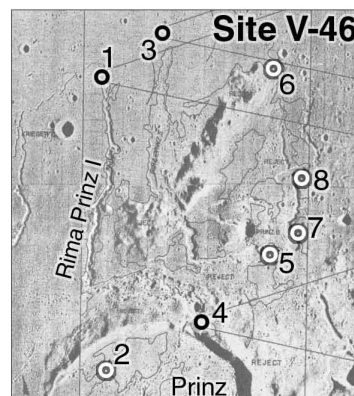
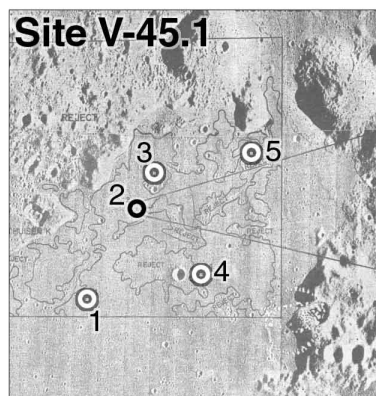
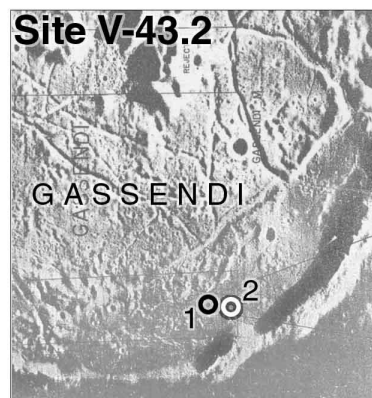
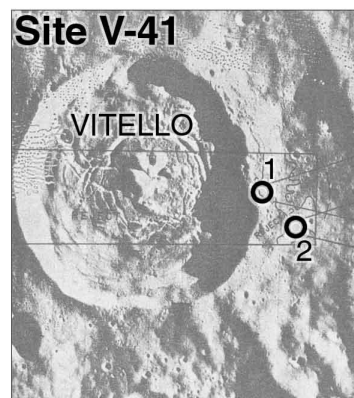
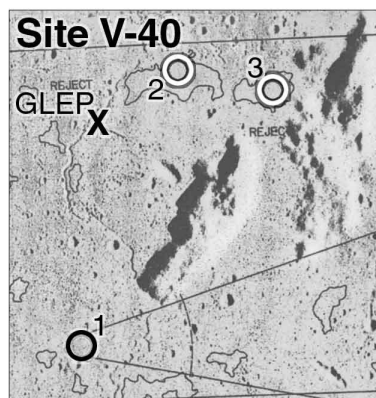
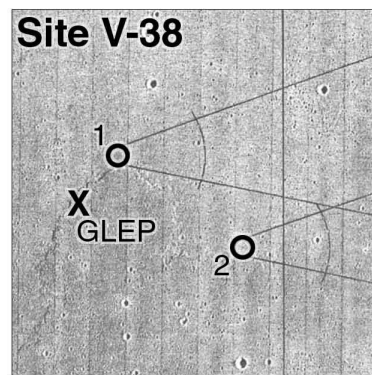
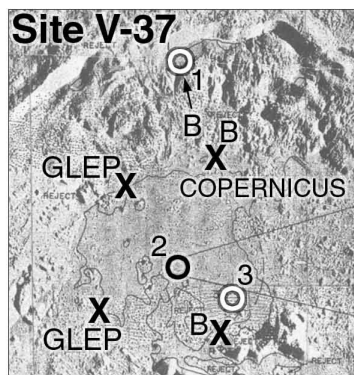
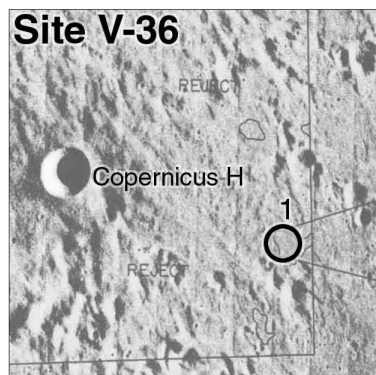


Figure 118. Set A potential sites, continued from Figure 117.

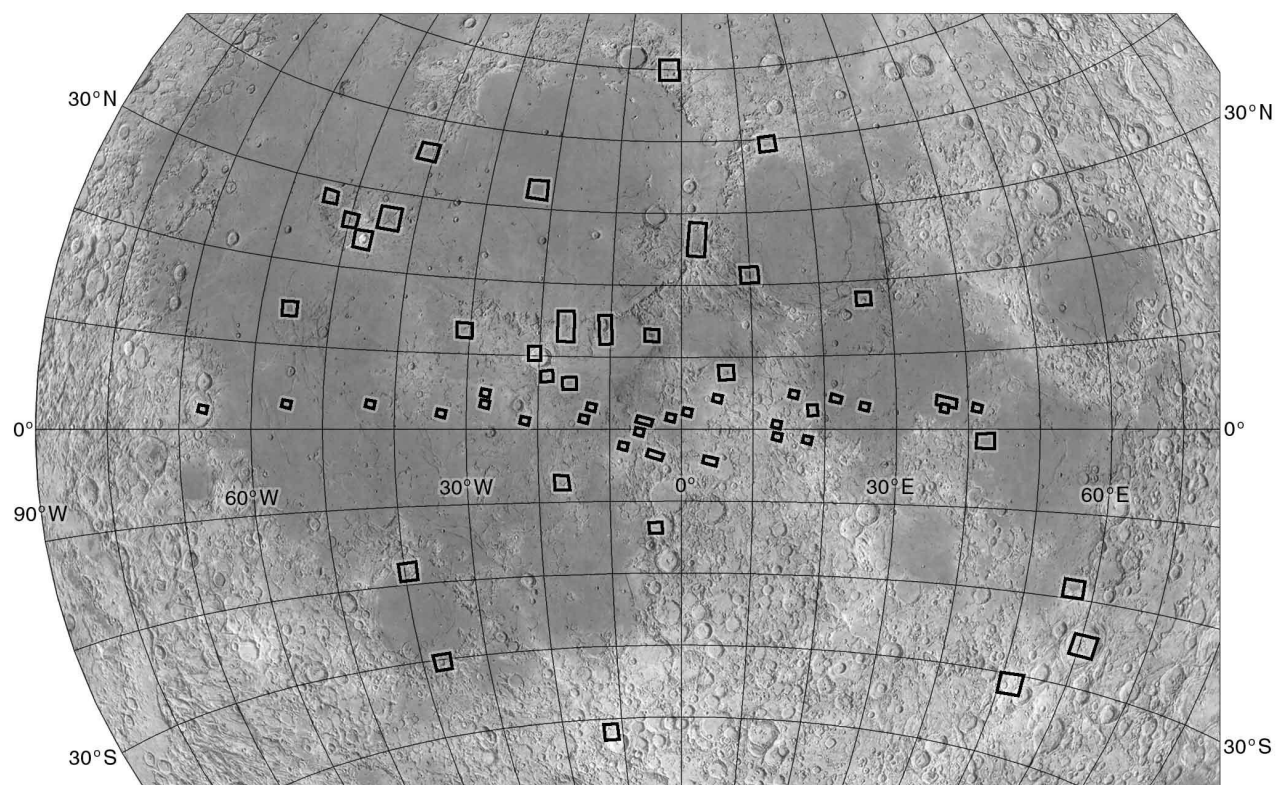
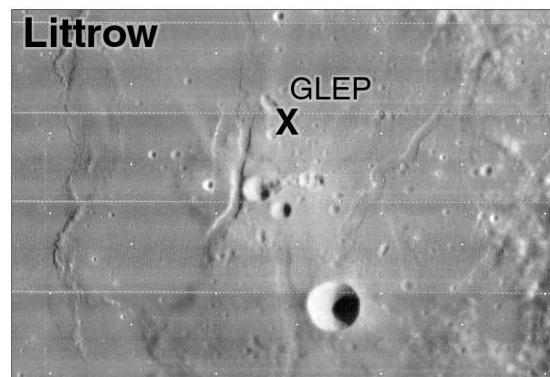
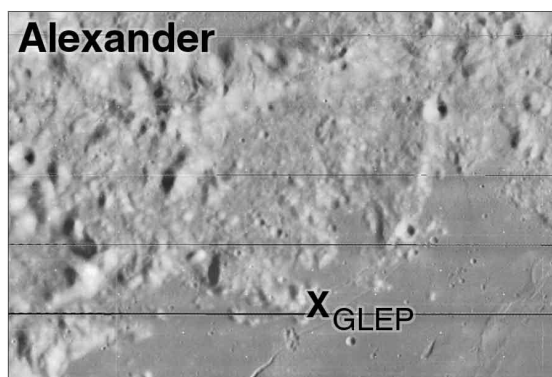
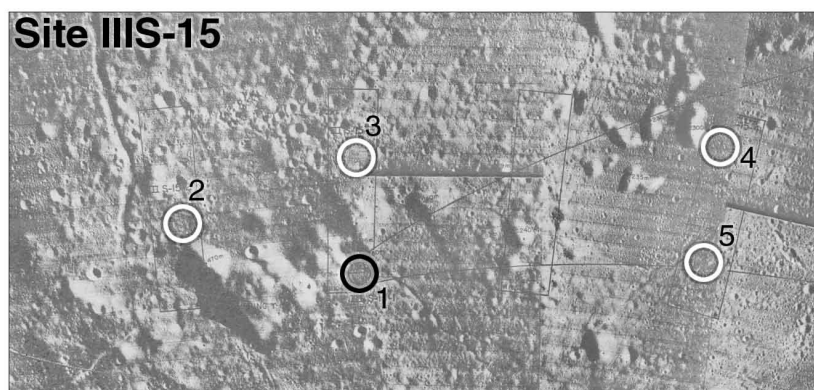
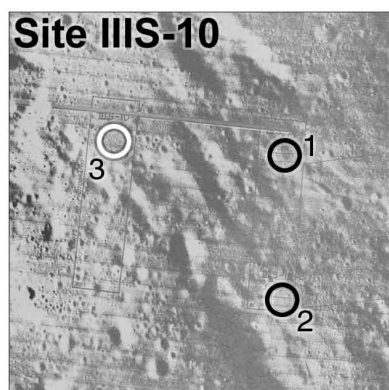


Figure 119. Set A potential sites, continued from Figure 118, and a map of all Set A sites from the report of the Surface Analysis Group (1968).

Table 36. Additional sites shown in Figures 114-119

36a. GLEP AAP sites, June 1968			36b. Bellcomm Apollo sites, 1968		
site	name	location	site	name	location
1/35	Littrow	22° 12' N, 29° 20' E	1	Censorinus	0° 23' S, 32° 32' E
2/41	Dionysius	2° 42' N, 18° 00' E	2	Abulfeda	14° 57' S, 14° 18' E
3/45	South of Alexander	38° 30' N, 13° 30' E	3	Littrow rilles	31° 44' N, 29° 02' E
4/46	Sulpicius Gallus	21° 00' N, 9° 20' E	4	Hadley Rille	24° 42' N, 2° 57' E
5/47	Hyginus Rille	8° 15' N, 6° 00' E	5	Hyginus Rille	24° 42' N, 6° 10' E
6/50	Hadley Rille	26° 12' N, 3° 00' E	6	Tycho ejecta	40° 54' S, 11° 21' E
7/53	Alphonsus	13° 40' S, 4° 10' W	7a	Copernicus peaks	9° 43' N, 20° 00' W
8/59	Copernicus CD	6° 25' N, 14° 45' W	7b	Copernicus wall	10° 51' N, 20° 09' W
9/60	Fra Mauro	7° 0' S, 16° 45' W	8a	Schröter's Valley S	24° 20' N, 49° 29' W
10/61	Copernicus secondaries	14° 40' N, 16° 15' W	8b	Schröter's Valley NE	25° 12' N, 49° 16' W
11/63	Copernicus (2 sites)	10° 25' N, 20° 18' W	8c	Schröter's Valley NW	25° 28' N, 49° 58' W
12/65	Imbrium flows	32° 40' N, 22° 00' W	9a	Marius Hills a	14° 35' N, 56° 37' W
13/69	Tobias Mayer Dome	13° 10' N, 30° 55' W	9b	Marius Hills b	14° 00' N, 55° 33' W
14/76	Jura-Gruithuisen	35° 55' N, 41° 30' W	9c	Marius Hills b	13° 24' N, 55° 30' W
15/82	Aristarchus	28° 00' N, 52° 45' W			
16/83	Marius Hills	13° 45' N, 56° 00' W			

El-Baz, F., 1968. *Geologic characteristics of the nine lunar landing mission sites recommended by the Group for Lunar Exploration Planning*. Bellcomm, Inc. report TR-68-340-1, 31 May 1968.

Silberstein, I., 1968. Comments on LM landing at nine potential science sites - case 340. Unpublished note, Bellcomm Inc.

Surface Analysis Group, 1968. *Screening for Lunar Exploration Landing Sites*. Mapping Sciences Branch, MSC, 27 May 1968.

Wilhelms D. E., 1993. *To a Rocky Moon: a geologist's history of lunar exploration*. Tucson: University of Arizona Press.



04-05 June 1968: Group for Lunar Exploration Planning

At this meeting GLEP considered landing options other than a sequence of separate sites. The principal alternative was multiple landings at one site to build up research infrastructure such as an observatory. A compromise would be to make more than one visit to each of several sites. A single site revisit program could evolve to an observatory for astronomy, bioscience and lunar exploration and exploitation, functional by 1980, supporting 12 people for one to two years.

During construction, shorter stays (up to about 12 days) would dictate an equatorial site to accommodate the Moon's rotation under the command module's orbit plane. A highland-mare contact would be advantageous for geological studies. Latitudes a little south of the equator would be best for an observatory so both galactic poles would be visible. These criteria could be difficult to combine at one site. Marius Hills and Mare Orientale were considered suitable areas, and an impact crater was suggested as an interesting type of target.

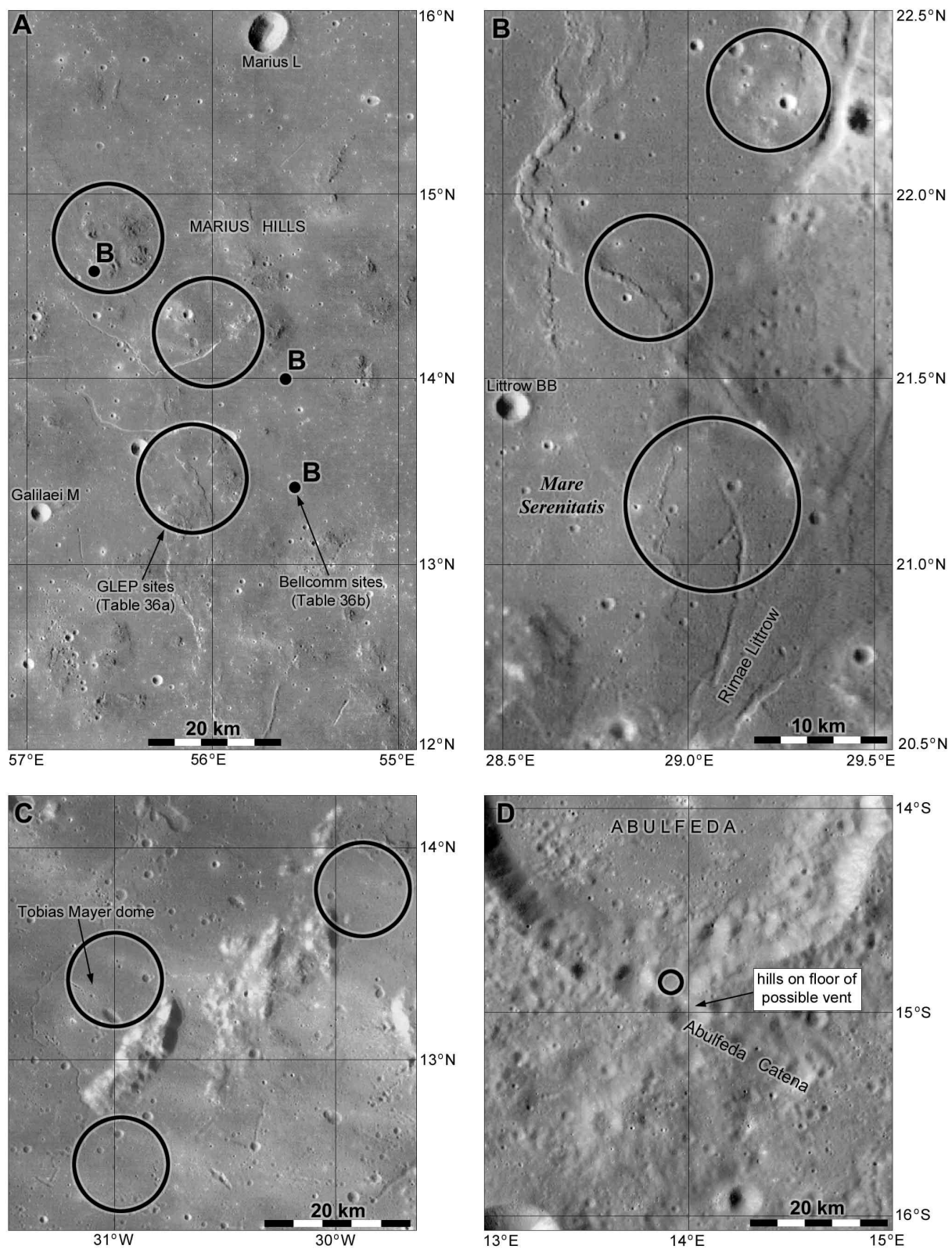


Figure 120. GLEP and Bellcomm sites for Apollo. A: GLEP and Bellcomm sites at Marius Hills. B: GLEP sites at Littrow. C: GLEP sites at Tobias Mayer. D: Bellcomm site at Abulfeda.

GLEP also considered the types of lunar feature that would be scientifically desirable for future landings (Table 37). Some sites already had sufficient photography, some required either a dual Saturn 5 launch or an extended version of the Lunar Module (LM). Theophilus West, proposed by Hal Masursky of the USGS, became the Apollo 16 site.

Table 37. Types of lunar feature to be targeted for future missions		
Feature type	Site	Comments
1. Impact features	Copernicus or Tycho (unmodified crater)	Dual launch, existing photography OK
	Posidonius or Gassendi (modified crater)	Extended LM, existing photography OK
	Mare Orientale or Mare Imbrium (large basin)	Dual launch
2. Volcanic features	Marius Hills	Dual launch, existing photography OK
	Schröter's Valley and Cobra Head	Dual Launch
	Theophilus West (upland volcanics?)	Extended LM
	Abulfeda or Davy crater chains	Extended LM, existing photography OK
	Rima Bode or Littrow Rille	Extended LM, existing photography OK
3. Tectonic features	Hyginus Rille	Extended LM, existing photography OK
	Apennine Front	
4. Lunar poles (added later)	Polar sites, possible trapped ice.	

The plan for the first three landing missions is summarized in Table 38. The evolution to greater capability is evident. The science sites for mission two would be redesignated sites like those shown in Figure 159. True pinpoint landing capability would begin with mission three.

Table 38. First three Apollo lunar landing missions considered by GLEP			
Mission number	Landing mission 1	Landing mission 2	Landing mission 3
Site	IIP-2, IIP-6, IIP-8, IIP-13, IIIP-11	Science sites in IIP-2, IIP-8, IIP-11 and IIIP-12	Censorinus
Objectives	Demonstrate landing and surface operations, deploy instruments, collect mare samples.	Study ridge, hill or Flamsteed ring structures, deploy instruments.	Demonstrate point landing, collect highland samples, deploy instruments.
Stay time	~26 hours, 2 EVAs	>26 hours, 3 EVAs	>26 hours, 3 EVAs

GLEP then turned its attention to possible astronaut surface activities (Extravehicular Activity, EVA) at several sites shown in Figure 121, which is derived from the materials presented at the meeting. Figure 121A shows the Marius Hills site and mission plan presented at the June 1968 GLEP meeting. The details were published in Karlstrom *et al.* (1968). The lander would be an extended Lunar Module equipped for a stay of several days.

Heavy lines in Figure 121A show rover routes (EVA 1 to EVA 4) for sampling at the black dot locations and deploying explosive charges for the Active Seismic Experiment (asterisks). Thinner lines show two LFU routes (F-1, F-2) to be flown to distant sites, the most distant being 5 km south of the LM. Communication repeater stations would be set up on peaks on those two routes, to allow uninterrupted radio communication with all sites and experiments.

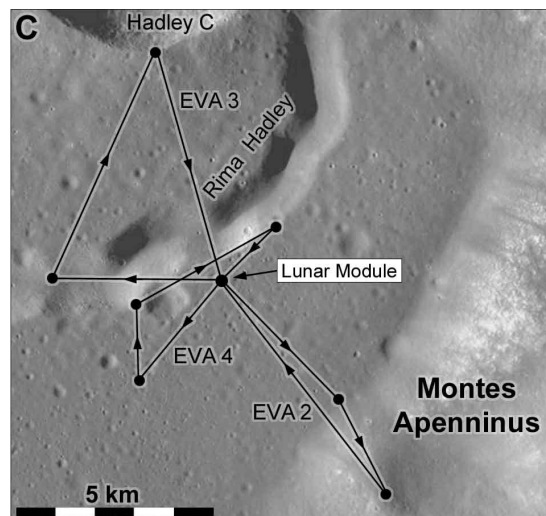
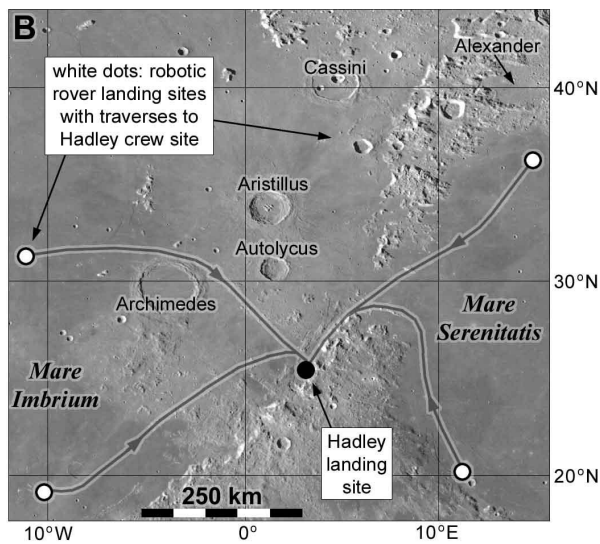
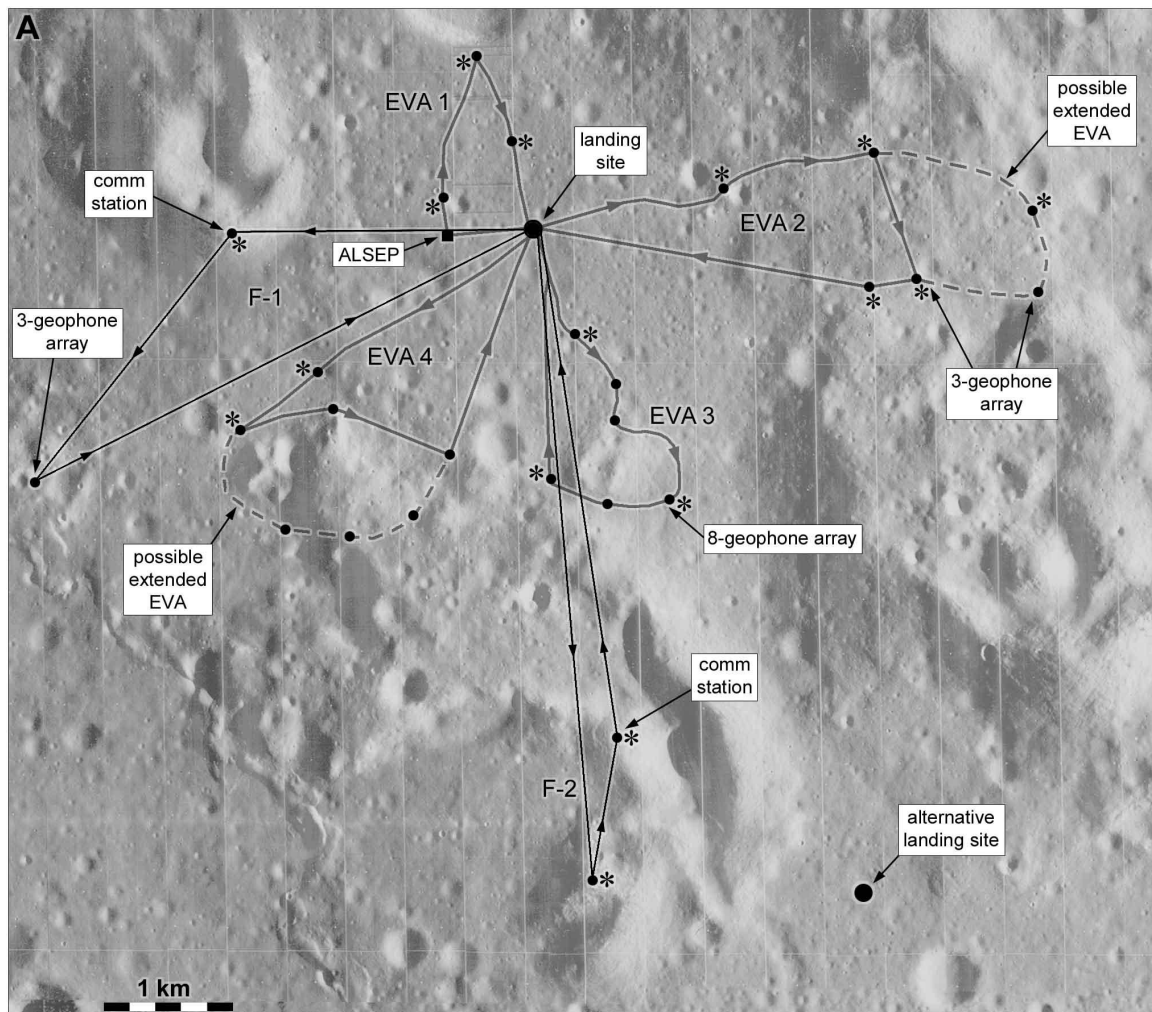


Figure 121. Apollo plans considered by GLEP in June 1968. A: Marius Hills EVA plans. The background image is Orbiter 5 frame 216-H3. B: Rover routes converging on the Hadley landing site. C: Hadley landing site EVAs.

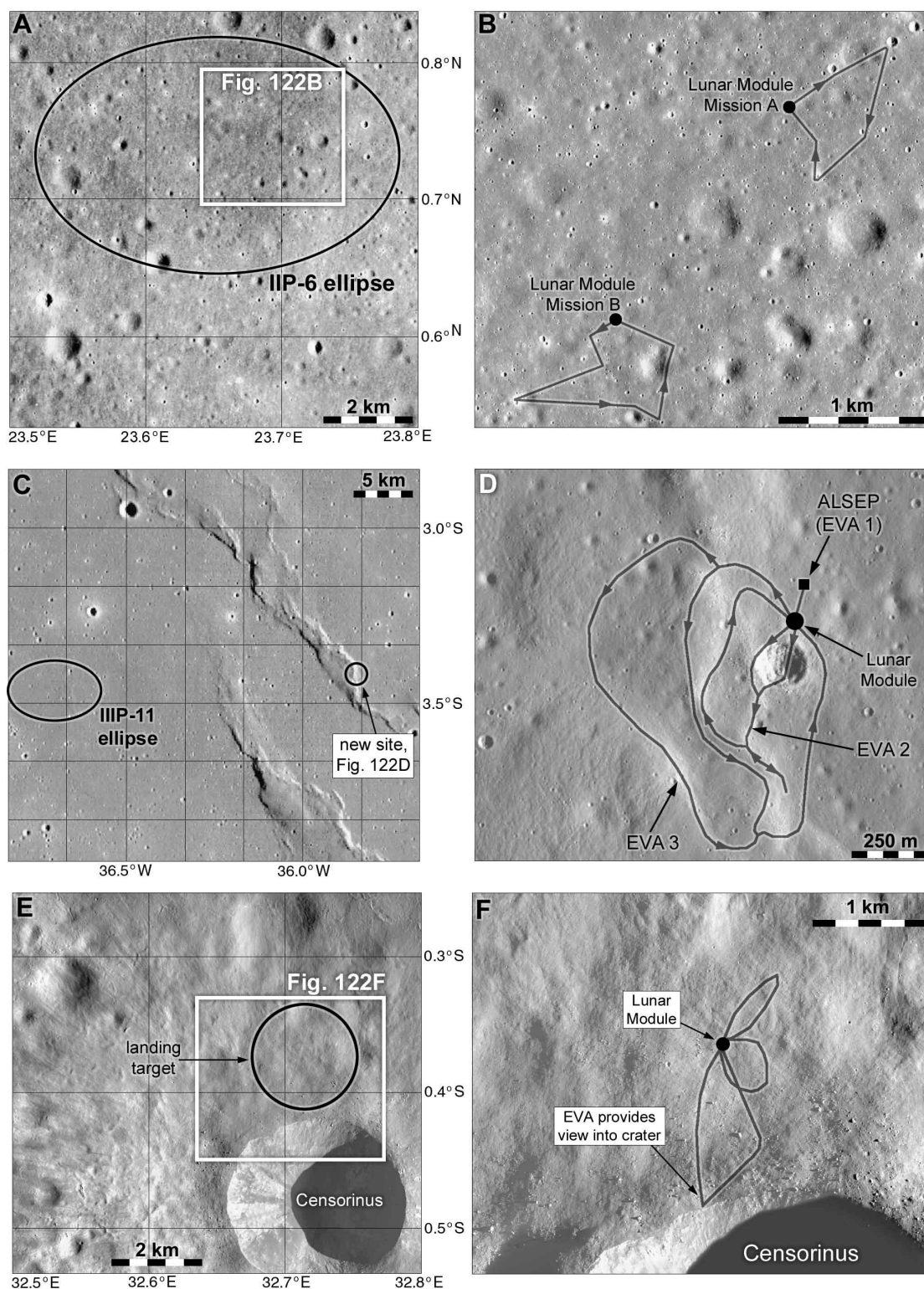


Figure 122. Apollo plans considered by GLEP in June 1968. A, B: the IIP-6 ellipse and EVAs. C, D: redesignated site for IIP-11 and EVAs. E, F: Censorinus EVA plans. A and C are LROC wide angle mosaics. B, D, E and F are LROC NAC mosaics.

Two geophone arrays set up at east and west extremes of the site would allow subsurface structural mapping as the various explosive charges were set off. An eight-geophone array set up on EVA 3 was designed to probe the deep structure of a small fracture in the crust at that location. Two of the EVAs might have been extended to allow further sampling if time and resources permitted. See also Figure 136 for a more advanced mission plan at the same site.

This meeting also considered a landing with extensive surface traverses in Mare Orientale. The Lunar Orbiters had shown this to be one of the most scenically dramatic and geologically interesting regions of the Moon. The Orientale mission is described separately with Figure 133B.

The GLEP meeting also considered a mission to the Hadley Rille (Rima Hadley) and the Apennine Mountains (Montes Apenninus), augmented by one or more rovers landed previously at sites several hundred km away. They could collect samples and data during long drives, controlled from Earth (Figure 121B). The Jet Propulsion Laboratory had devised remote-controlled rover concepts for sample collection, *in situ* analysis and geophysical measurements. Eventually the crew would land and gather the samples to supplement their own local fieldwork. The proposed landing point is 40 km southwest of the eventual Apollo 15 site. The first EVA for ALSEP deployment and sample collection (not shown) remained close to the lunar module. ALSEP is the Apollo Lunar Surface Experiment Package, a set of instruments to be set up by the crew during the first EVA, first flown on Apollo 12.

Figure 121C illustrates three Lunar Flying Unit (LFU) flight lines. The three long LFU flights gave access to the mountains, the floor of the steep-walled valley and the rim of crater Hadley C, as well as additional mare sampling sites. The LFU would have been essential for the thorough exploration of rugged sites such as Hadley and Marius, as these missions were envisaged at this time. This one-person rocket-propelled structure would be flown in a standing position. Planners often assumed they would eventually have this capability, but in the end this inherently dangerous device was never built.

Figure 122 illustrates three sites suitable for early Apollo missions, with possible EVAs. Figures 122A and 122B show the landing ellipse in site IIP-6, the Apollo 11 landing area. Two plausible EVAs are depicted. For that first mission a pinpoint landing at the centre of the ellipse was not expected and no pre-planned traverses were laid out, because the expected walking distance was much smaller than the likely distance from the target. These two paths are representative of the short traverses that might be possible. Figures 122C and 122D show a redesignated site in IIIP-11 with three EVAs on the flank of a mare ridge. Figures 122E and 122F show the Censorinus North site (Figure 113H) and possible EVAs on the crater's ejecta blanket. At the southern limit of their walk the crew would have a dramatic view into the 4 km wide crater.

Table 39 is a composite of several tabulations presented at the June GLEP meeting. It represents the 'Set A' sites described above. The table lists 88 landing targets, classifying them as good, fair or poor, and identifies with asterisks the 23 considered most promising for further study. These would be the 'Set B' sites. This table can be compared with Figures 56, 70 and 84 (Chronicle volume 2) to identify orbiter imaging sites and specific landing targets. The same numbering system is used for the table and figures. Tables 39a and 39b are sites shown in higher resolution imaging, and Table 39c lists the sites with less adequate imaging.

Table 39. Set A candidate Apollo sites presented at the June 1968 GLEP meeting

39a. Set A candidate Apollo sites with higher resolution photography				
site	target	name	rating * favoured for further analysis	location
IIP-1	1	Maskelyne F	good *	4° 02' N, 36° 20' E
	2	Maskelyne F	good	4° 00' N, 37° 45' E
IIS-1	1	Secchi A	good *	3° 25' N, 41° 05' E
IIS-2	2	south of IIP-1	good *	3° 35' N, 36° 43' E
IIP-5	1	Sabine EA	good *	2° 43' N, 24° 33' E
	2	Sabine EA	good	3° 04' N, 25° 18' E
IIP-7	2	Pallas FA	good *	1° 52' N, 1° 51' W
IIS-9	1	north of Bruce	good	2° 34' N, 3° 33' E
IIS-17	1	Hipparchus	good	4° 32' S, 3° 53' E
	2	Hipparchus	good	4° 50' S, 4° 24' E
	3	Hipparchus	good *	5° 09' S, 4° 46' E
IIS-19	3	Flammarion	good *	3° 17' S, 3° 18' W
IIS-22	1	Reinhold β	good	0° 56' N, 22° 00' W
IIS-31	1	Hevelius	good	2° 10' N, 66° 28' W
V-2.1	1	Petavius B	good	18° 49' S, 57° 15' E
	2	Petavius B	good	18° 46' S, 57° 26' E
V-8	1	IP-1	good *	0° 57' S, 42° 20' E
	5	IP-1	good	0° 55' S, 43° 40' E
V-15.1	1	Dawes	good	17° 24' N, 26° 59' E
V-22	1	Sulpicius Gallus	good *	20° 40' N, 9° 40' E
V-23.1	1	Hyginus Rille	good	7° 26' N, 6° 06' E
	2	Hyginus Rille	good *	7° 35' N, 6° 28' E
V-28	1	Alphonsus	good *	13° 20' S, 3° 15' W
V-32	3	Eratosthenes	good	12° 48' N, 10° 15' W
	4	Eratosthenes	good *	10° 22' N, 10° 12' W
V-33	3	Copernicus CD	good	6° 45' N, 14° 20' W
V-34	5	Fra Mauro	good *	7° 10' S, 16° 20' W
V-35	1	Copernicus secondaries	good	12° 40' N, 16° 08' W
	2	Copernicus secondaries	good	12° 45' N, 16° 10' W
	3	Copernicus secondaries	good *	16° 20' N, 16° 13' W
	4	Copernicus secondaries	good	16° 25' N, 16° 15' W
V-37	2	Copernicus	good *	9° 55' N, 20° 16' E
V-40	1	Tobias Mayer domes	good *	12° 35' N, 31° 0' W

Table 39 (continued)

39b. Set A candidate Apollo sites with higher resolution photography (continued)				
site	target	name	rating * favoured for further analysis	location
V-48	1	Aristarchus	good *	21° 52' N, 46° 54' W
V-51	1	Marius Hills	good	13° 36' N, 56° 25' W
	2	Marius Hills	good	13° 11' N, 55° 50' W
	3	Marius Hills	good *	13° 40' N, 55° 48' W
	4	Marius Hills	good	13° 25' N, 55° 38' W
IIP-3	1	Manners	fair	4° 12' N, 21° 03' E
	3	Manners	fair	4° 25' N, 21° 12' E
	5	Manners	fair	4° 05' N, 21° 33' E
IIP-4	1	Rima Ariadaeus	fair	5° 02' N, 16° 10' E
IIP-7	1	Pallas FA	fair	1° 56' N, 1° 55' W
IIP-9	2	Gambart G	fair	0° 55' N, 12° 55' W
IIP-10	1	Hortensius dome	fair	3° 08' N, 27° 14' W
IIP-12	1	Kunowsky	fair	1° 42' N, 34° 12' W
	2	Kunowsky	fair	1° 40' N, 33° 53' W
IIS-8	2	Lade A	fair	0° 20' N, 12° 55' E
IIS-13	1	south of Suess D	fair	3° 05' N, 42° 35' W
	2	south of Suess D	fair	2° 55' N, 42° 37' W
IIS-16	1	west of Reiner C	fair	2° 50' N, 53° 35' W
IIIS-9	1	Delambre	fair	1° 42' S, 17° 32' E
IIIS-18	3	Mösting C	fair	1° 45' S, 7° 45' W
V-18	1	Dionysius	fair	3° 08' N, 18° 03' E
V-24	1	Hipparchus	fair	4° 40' S, 3° 35' E
V-29	1	Rima Bode II	fair	12° 41' N, 4° 32' W
V-32	1	Eratosthenes	fair	15° 25' N, 10° 17' W
	2	Eratosthenes	fair	13° 58' N, 10° 23' W
V-36	1	Copernicus H	fair	6° 35' N, 17° 35' W
V-43.2	1	Gassendi	fair	19° 04' S, 39° 28' W
IIP-4	2	Rima Ariadaeus	poor	4° 27' N, 16° 07' E
IIS-6	1	Rima Triesnecker II	poor	4° 22' N, 4° 38' E
IIS-8	1	Lade A	poor	0° 42' N, 12° 58' E
IIS-0.2	2	Gambart C	poor	3° 25' N, 11° 25' W
IIS-11	1	Hortensius EB	poor	4° 58' N, 27° 10' W
IIIS-16	1	Mösting	poor	0° 16' S, 5° 31' W

Table 39 (continued)				
39c. Set A candidate Apollo sites with lower resolution photography				
site	target	name	rating * favoured for further analysis	location
V-1	2	Petavius	good	25° 20' S, 60° 10' E
	5	Petavius	good *	25° 00' S, 61° 35' E
V-4	1	Stevinus A	good	31° 20' S, 51° 30' E
	2	Stevinus A	good	31° 15' S, 52° 10' E
V-26.1	2	Hadley-Apennine	good *	25° 05' N, 2° 50' E
V-41	2	Vitello	good	30° 45' S, 36° 29' W
V-45.1	2	Jura domes	good *	35° 31' N, 41° 29' W
V-46	1	Montes Harbinger	good *	28° 10' N, 44° 20' W
V-50	1	Aristarchus plateau	good *	28° 48' N, 53° 30' W
V-21	1	south of Alexander	fair	39° 40' N, 14° 45' E
V-26.1	1	Hadley-Apennine	fair	26° 30' N, 2° 40' E
	3	Hadley-Apennine	fair	28° 10' N, 4° 02' E
V-31	1	east of Plato	fair	49° 50' N, 4° 05' W
	2	east of Plato	fair	49° 30' N, 3° 20' W
	4	east of Plato	fair	48° 50' N, 0° 45' W
V-38	1	Imbrium flows	fair	32° 47' N, 21° 55' W
	2	Imbrium flows	fair	32° 11' N, 21° 15' W
V-46	3	Montes Harbinger	fair	28° 30' N, 44° 20' W
	4	Montes Harbinger	fair	26° 15' N, 43° 35' W
V-49	1	Cobra Head	fair	25° 36' N, 50° 02' W
V-30	1	Tycho	poor	41° 06' S, 11° 57' W
V-41	1	Vitello	poor	30° 27' S, 36° 40' W

Karlstrom, T. N. V., McCauley, J. F. and Swann, G. A., 1968. Preliminary lunar exploration plan of the Marius Hills region of the Moon. *Astrogeology* 5, USGS open-file report.



25 July 1968: Group for Lunar Exploration Planning

At this meeting GLEP considered program goals beyond the first landing. Kennedy's original goal would have been fulfilled by a single successful landing and return. Several options were outlined. Apollo could be ended after either three or six landings at different sites. It could pause after three landings to assess results, and then continue. Crews could continue to land, augmented by robotic missions. They could continue to land with upgraded equipment giving greater exploration potential. Apollo could end after three landings, followed by a robotic program. Finally, the single site option outlined at the previous meeting could be pursued. The meeting also identified specific problems in lunar science and sites which would address them (Table 40), placing site selection on a scientific rather than operational basis.

GLEP identified fifteen sites as needing further photography for landing assessment: Gambart (questionable), Gambart C, Mösting, Mösting C, Hevelius, Posidonius, Descartes, Boscovich, Davy, Censorinus, Dawes, Abulfeda, Rima Hadley, Copernicus CD and Vitello.

They recommended analysis of the following potential future sites in Fiscal Year (FY) 1969: Early Apollo sites at Mösting C, Censorinus, Fra Mauro and Hipparchus; Late Apollo (with extended LM) sites at Littrow, Hyginus, Tycho and Gassendi, and Dual-launch mission sites at Marius Hills, Hadley-Apennines, Copernicus and Harbinger mountains. In FY 1970 the Late Apollo sites at Abulfeda, Rima Bode II, Schröter's Valley/Aristarchus Plateau, Aristarchus crater, Dionysius, south of Alexander, Tobias Mayer dome and Copernicus CD, and the dual-launch site at Alphonsus should be analysed.

Table 40. Site considerations: Lunar geological units and problems.					
Major surface units			Regional Lunar Problems		
1. Mare		Eastern mare	problem		area
		Western mare/ Flamsteed ring			
2. Highlands		Censorinus	1. Configuration and composition of mare basins	Filled basins	Imbrium/ Serenitatis
				Unfilled basins	Orientale
Major processes			2. Configuration and composition of highland basin		Clavius/ Hipparchus
3. Impact	Small fresh craters	Censorinus	2a. Difference between 1 and 2		
	Large fresh craters	Copernicus/ Tycho			
	modified craters	Posidonius/ Gassendi	3. Structure and composition of highlands		Apennines/ Serenitatis rim
4. Volcanism	Variety of forms	Marius Hills	4. Basement under regional ejecta blanket		North of Fra Mauro
	Recent activity?	Schröter's Valley	5. Major volcanic province		Marius Hills
	In highlands	Abulfeda/ Davy/ Descartes	6. Structure of major valley		Alpine Valley
	Associated with rilles	Littrow/ Rima Bode II	7. Major fault zones		Straight Wall/ Rheita Valley
5. Mountains and faults	Mountain front	Apennine scarp	8. Origin and formation of major sinuous rilles		Prinz rilles/ Hadley Rille/ Schröter's Valley
	Major fault trough	Hyginus Rille			



15 September 1968: Zond 5

The 5375 kg Zond 5 was launched at 21:42 UT into an Earth parking orbit, then injected into a lunar trajectory from its Tyazheliy Sputnik platform. The mission was a systems and hardware test for future human exploration missions, with an opportunity to make scientific studies during a lunar flyby, culminating with a return to Earth. A life sciences experiment involving turtles, flies, worms, plants, seeds, bacteria, and other living things was conducted.

On 18 September the spacecraft flew around the Moon at a minimum distance of 1950 km. Photographs of the Earth were obtained from 90 000 km altitude. Lunar photography was planned, but difficulty in controlling attitude during the flyby prevented it. On 21 September the spacecraft re-entered the Earth's atmosphere, braked successfully and parachuted to a splashdown in the Indian Ocean. The film and the biological payload were recovered successfully. The mission was a precursor to a human lunar expedition, the first circumlunar flight with a return to Earth since Luna 3, and its passengers were the first living things to make a round trip to the Moon.

There had been two precursor missions since Zond 4. On 22 April the launch escape system on a similar spacecraft malfunctioned during launch. It automatically shut down the second stage engines 260 seconds after liftoff. The escape rockets pulled the spacecraft away from the launcher and it was recovered safely. On 21 July the upper stage of a similar launcher exploded on the launchpad, killing three people but leaving the spacecraft intact.



26 September 1968: Apollo Site Selection Board

The effects of irregularities in the lunar gravitational field on orbiting spacecraft were still poorly understood at this time, making the position of the spacecraft along its descent trajectory uncertain by up to ten kilometers, about twice what had been expected in initial planning. This necessitated a last-minute change in the size of the landing ellipses for the first landing mission. At this meeting the Board approved elongated ellipses, 5.0 by 15.0 km, for the Set C sites, the five primary targets for the first Apollo landing mission (Figure 123). The previously favoured ellipses, 5.3 by 7.9 km, are shown as thinner outlines in that illustration. They also considered sites for the second landing mission, again looking at 1 km radius circles near points of scientific interest. These sites, referred to as redesignated sites in the 26 March 1968 meeting, were now called relocated or biased sites.

Biased sites were described at this meeting for four of the Set C sites (IIP-2, IIP-6, IIP-8, IIP-11) and for site IIP-12 (near Surveyor 1). The minutes state: “The capability to land near the feature of interest is to be provided by pilot redesignation during the latter part of the LM descent.” Descent targeting would bring the LM into the landing area, and the pilot would take over to reach the biased site itself. Biased sites IIP-2, IIP-8 and IIP-12 are illustrated in Figure 112, Site IIP-11 in Figure 122. The IIP-6 biased site is illustrated in Figure 123. Base maps are from Figure 151.

Next, the sequence of sites for landing missions 1, 2 and 3 was considered. At this time it was not certain that Apollo 11 would be the first landing mission, so formal mission numbers were not assigned. The first landing would take place in one of the five smooth mare sites (Set C).

A conservative sequence would place the second landing at another of those sites, and a third at one of the five biased sites just described, or possibly at one of the scientifically interesting ‘exploration sites’ within the formal Apollo zone (Figure 34A). These were Censorinus, Fra Mauro, Mösting C or Hipparchus. A more aggressive expansion of capability, assuming no setbacks in previous missions, would place the second landing at one of the five biased sites. Then the third landing could go to one of the exploration sites in the Apollo zone, or possibly to an exploration site outside the Apollo zone. The candidates here were Hyginus, Tycho rim, Littrow or Gassendi.

Reaching sites outside the Apollo Zone required a more complex and risky flight profile. The early Apollo flights followed a free return trajectory: if not inserted into lunar orbit, the spacecraft would loop around the Moon and return directly to Earth. The new trajectories would involve a change in the lunar orbit plane to reach higher latitude sites. The initial orbit would be highly elliptical with a 24 hour period. At the high point a rocket burn changed the orbit plane, and at the next low point a second burn made the orbit circular at about 100 km altitude. Calculations showed that most sites could be reached in this way, only Schröter’s Valley being marginally accessible.

For the later Apollo missions, a large Set A of potential sites had been described at the June GLEP meeting (Table 39). Following further screening at MSC, the Group now designated 21 Set B candidate sites (Table 41 and Figures 124-127) for detailed analysis, some differing slightly from those considered before. Another report by the Apollo Lunar Exploration Office (ALEO 1968) also identified later landing sites. Its sites at Censorinus (West), Littrow and Abulfeda are as suggested on 26 March 1968. Sites which differ from this Set B are labelled ALEO in Figures 124-127. Table 41 is compiled from two lists in the ASSB minutes which contain numerous inconsistencies. The Apennines-Hadley site was later referred to as Hadley-Apennines.

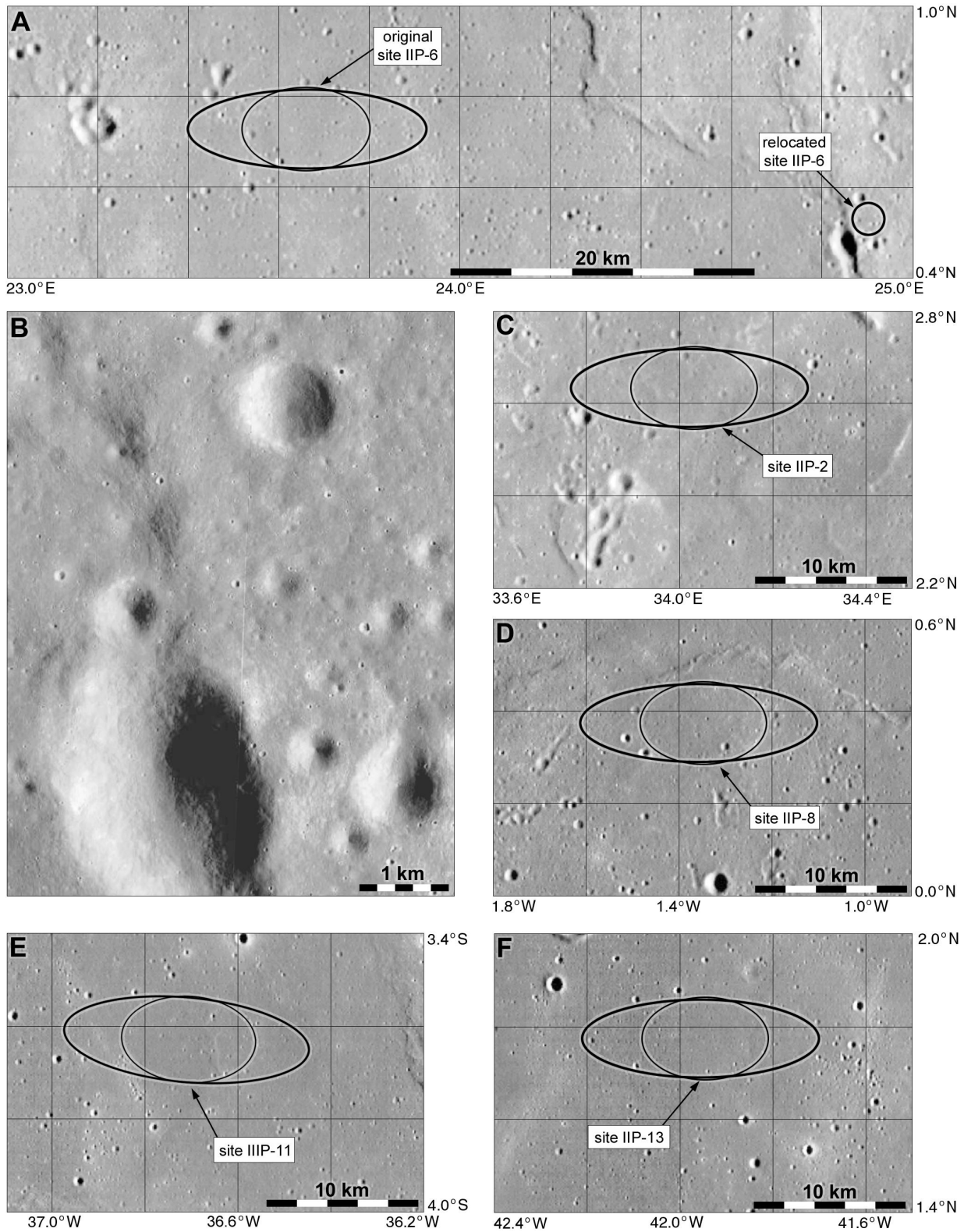


Figure 123: Extended ellipses for Apollo Set C sites. The larger ellipses accommodate uncertainties in position caused by mascons. Figure 123A also shows the relocated site at IIP-6, and Figure 123B is an LROC NAC mosaic of that location.

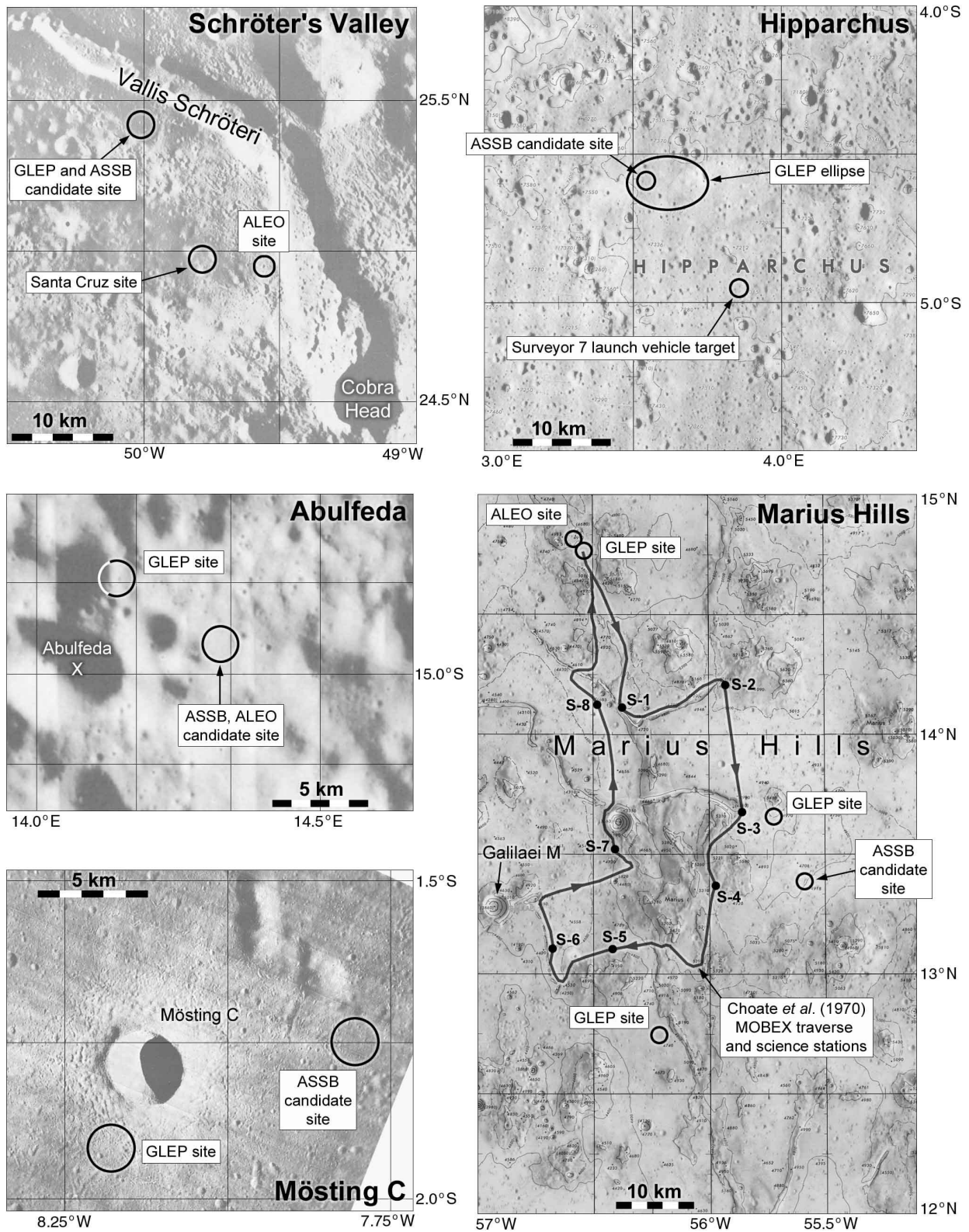


Figure 124. Set B landing sites for Apollo, from Table 41. Sites suggested by ASSB, GLEP and the Apollo Lunar Exploration Office (ALEO) are labelled and a contemporary traverse plan is added at Marius Hills..

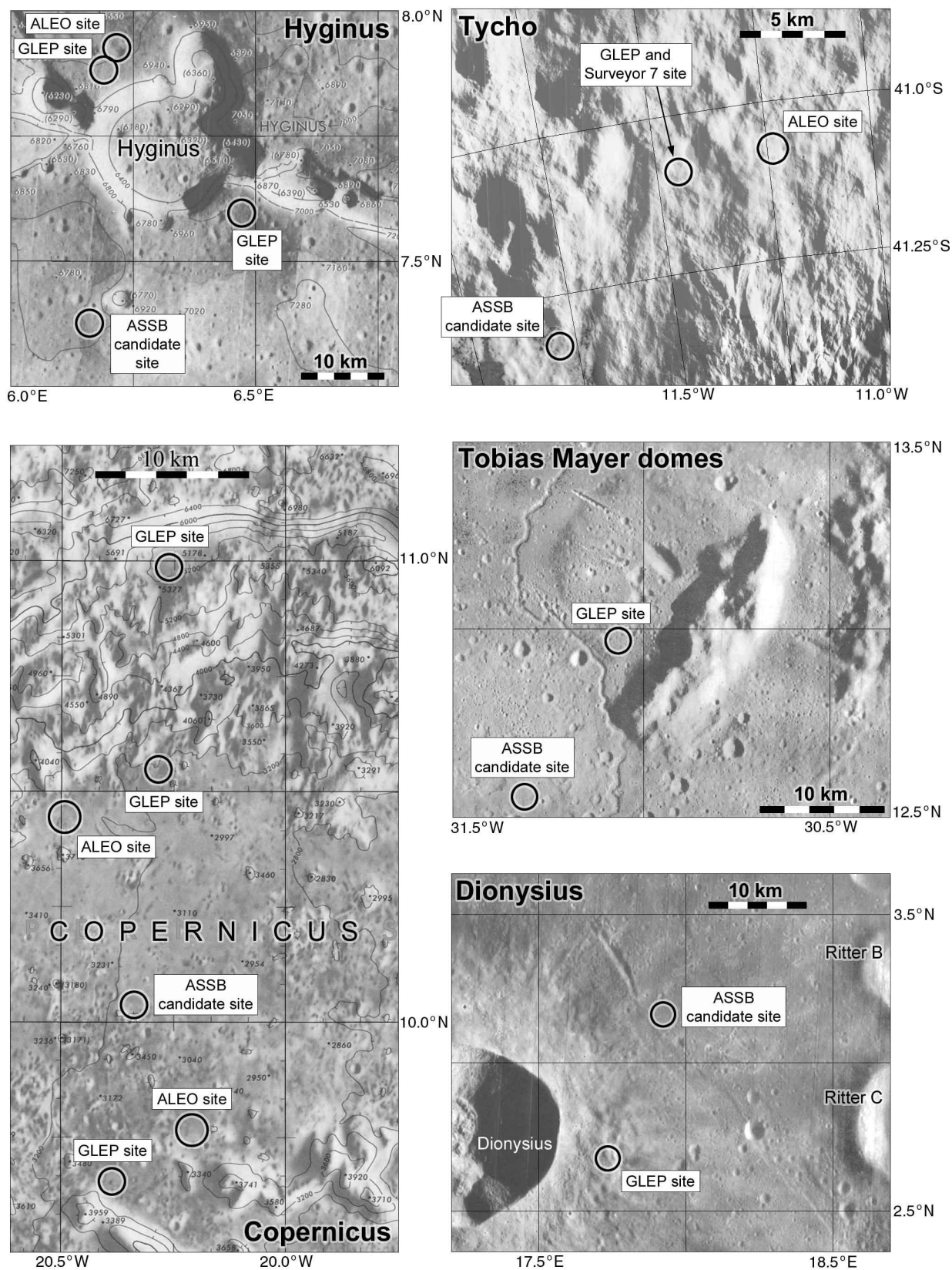


Figure 125. Set B landing sites for Apollo, continued from Figure 124.

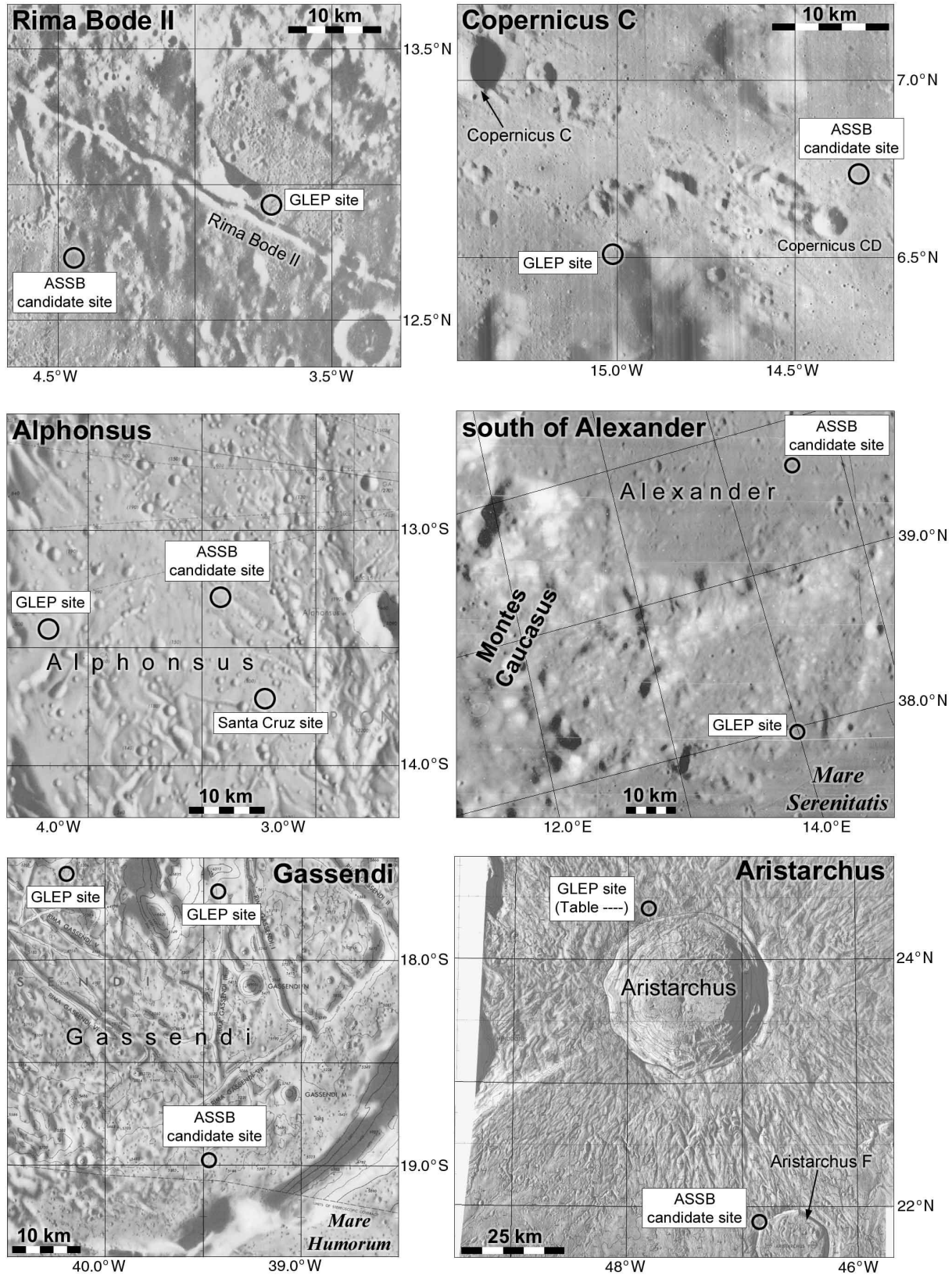


Figure 126. Set B landing sites for Apollo, continued from Figure 125.

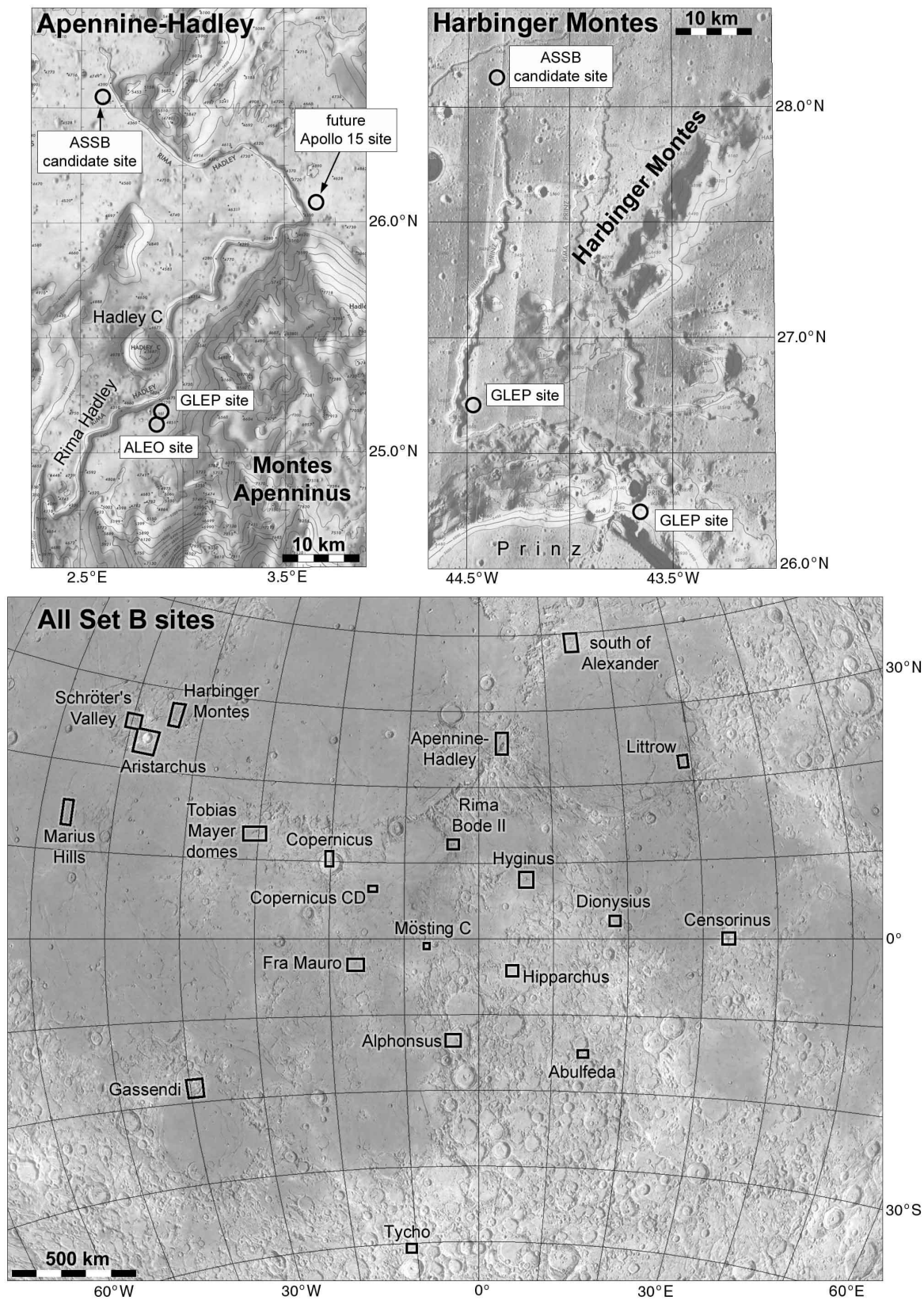


Figure 127. Set B landing sites for Apollo, continued from Figure 126, and locations of all Set B sites.

Table 41. Set B candidate sites for later Apollo landings.

site	name	coordinates	offset
IIIS-18	Mösting C	1° 45' S, 7° 45' W	11
IIIS-23	Fra Mauro	3° 45' S, 17° 36' W	0
V-12	Censorinus	0° 17' S, 32° 39' E	0
V-14	Littrow	21° 44' N, 29° 02' E	1
V-18	Dionysius	3° 08' N, 18° 03' E	15
V-19	Abulfeda	14° 57' S, 14° 18' E	6
V-21	south of Alexander	39° 40' N, 14° 45' E	52
V-23.1	Hyginus	7° 26' N, 6° 06' E	11, 12
V-24	Hipparchus	4° 40' S, 3° 35' E	3
V-26.1	Apennines-Hadley*	26° 30' N, 2° 40' E	39
V-28	Alphonsus	13° 20' S, 3° 15' W	20
V-29	Rima Bode II	12° 41' N, 4° 32' W	23
V-30	Tycho	41° 06' S, 11° 57' W	11
V-33	Copernicus CD	6° 45' N, 14° 20' W	22
V-37	Copernicus	9° 55' N, 20° 16' W	11, 14, 27
V-40	Tobias Mayer dome	12° 35' N, 31° 20' W	14
V-43.2	Gassendi	19° 04' S, 39° 28' W	22
V-46	Montes Harbinger	28° 10' N, 44° 20' W	41, 57
V-48	Aristarchus	21° 52' N, 46° 54' W	32, 82
V-49	Schröter's Valley/ Aristarchus plateau	25° 36' N, 50° 02' W	0
V-51	Marius Hills	13° 36' N, 56° 25' W	8, 27, 47
Note: the offset is the distance in km from this site to the GLEP preferred site. *Apennines-Hadley coordinates are changed to correct an error in the original documents.			

Of the 21 candidate Set B sites, Fra Mauro and Censorinus were as illustrated in Figure 113, and the favoured Littrow site was centred only 1 km southwest of the site shown in Figure 113. The remaining 18 sites are illustrated in Figures 124-127 using contemporary basemaps to illustrate the available materials, and the locations of all 21 sites are shown in Figure 127. A Working Group on Extraterrestrial Resources met annually during the Apollo period, holding their 7th meeting in June 1969. A presentation by Choate *et al.* (1970) described a mission to the Marius Hills which would use a MOBEX rover (Figure 124). This began as a student project at the Air Force Institute of Technology at the Wright-Patterson Air Force Base in Ohio in 1968. The mission would spend 90 days on the Moon with six astronauts and a mobile habitat (MOBEX) delivered by two Saturn 5 launches. A cargo launch would bring a habitat and the MOBEX unit plus all equipment and supplies to the GLEP landing site in the northern Marius Hills, and the crew would be delivered by the second launch up to 6 months after the cargo flight.

Now the full Set A list of potential sites (Table 39, Figures 114-119) had been reduced to a shortlist of potential sites, Set B, chosen on the basis of operational suitability, safety and scientific desirability. Many of the sites shown in Figures 124-127 differ from those shown in earlier figures. Numerous lists and revisions were being circulated simultaneously as the process gradually converged on a final site list. The base map and image details for Figures 124-127 are given below.

Choate, J. S., Mosbruger, C.D., Kemp, V.M. *et al.*, 1970. A manned lunar mission for water exploration in the Marius hills. in *Proceedings of the seventh annual working group on extraterrestrial resources*, held on 17-18 June 1969 at Denver, Colorado, pp. 75-86. NASA report SP-229, Washington, D.C.: NASA.

Schröter's Valley: Orbiter 5 frame 202-M. **Abulfeda:** Orbiter 5 frame 084-M. **Mösting C:** Orbiter 3 frame 113-M. **Hipparchus:** U. S. Army Lunar Topographic Map *Hipparchus* (Orbiter V site 24), original scale 1:250 000, 1st edition November 1970. **Marius Hills:** U.S. Army Lunar Topographic Map *Marius F*, (Orbiter V site 51), original scale 1:250 000. 1st edition April 1971. **Hyginus:** U. S. Army Lunar Topographic Photomap *Rima Hyginus* (Orbiter V site 23.1), original scale 1:250 000, 1st edition October 1970. **Copernicus:** U.S. Army Lunar Topographic Map *Copernicus*, (Orbiter V site 37), original scale 1:250 000. 1st edition January 1971. **Tycho:** Orbiter 5 frame 128-H. **Tobias Mayer:** Orbiter 5 frame 164-M. **Dionysius:** Orbiter 5 frame 081-M. **Rima Bode II:** Orbiter 5 frame 122-M. **Gassendi:** U.S. Army Lunar Topographic Map *Gassendi, Sheet B*, Orbiter V site 43.2, original scale 1:250 000, 1st edition December 1971. **Copernicus CD:** Lunar Orbiter 5-137-M. **South of Alexander:** Lunar Orbiter 4-98-H2. **Aristarchus:** ACIC Lunar Topographic Map *Aristarchus*, Orbiter V site 48, original scale 1:250 000, 1st edition January 1972. **Apennines-Hadley:** U.S. Army Lunar Topographic Map *Rima Hadley, Sheets A and B*, Orbiter V site 26.1, original scale 1:250 000, 1st edition January 1971. **Montes Harbinger:** U. S. Army Lunar Topographic Photomap *Prinz*, Orbiter V site 46, original scale 1:250 000, 1st edition December 1970.



10 November 1968: Zond 6

The Soviet Union's 5375 kg Zond 6 spacecraft was launched from Baikonur at 19:12 UT, placed in a parking orbit, and then sent on a lunar flyby mission and return to Earth. The Zond was very similar to Zond 5 and carried instruments including cosmic-ray and micrometeoroid detectors, cameras and a biological payload, but was primarily a test of lunar human spaceflight systems and hardware.

Zond 6 flew around the moon on 14 November with a closest approach of 2420 km. Photographs of the lunar surface were taken during the flyby, from distances of about 11,000 km (full disk images) and 3300 km (earthset images and regional coverage). Zond 6 successfully re-entered the Earth's atmosphere on 17 November and landed in the Soviet Union, but the landing was very hard and the capsule was badly damaged, including the camera. The biological cargo included two turtles which had already died due to an unintended loss of pressure in the cabin, and any surviving organisms (probably including flies and worms) were killed on impact with the ground. The film roll was flattened and damaged. Many frames were lost but some were saved, including enough material to piece together a single mosaic image of the photographed area. Information and images for Zonds 6, 7 and 8 were provided by K. Shingareva and B. Krasnopevtseva of MIIGAiK, Moscow.

Figure 128A is a full disk image from Zond 6, centred at about 90° W, 10° N. Mare Orientale is the dark spot below center. Careful measurement of the shape of the limb (edge of the disk) in this view revealed the existence of a deep depression in the southern farside (Rodionov *et al.*, 1971). This was the first hint of the existence of the giant South Pole-Aitken basin, a feature later confirmed in Clementine data. In Figure 128B a half-illuminated Earth is visible above the lunar horizon shortly before it set as viewed from Zond 6. The horizon in this view is near 90° W, 10° N. Grid lines on the Soviet original are drawn with 10° spacing.

Figure 128C is a mosaic of most of the area viewed by Zond 6, pieced together from surviving pieces of film after the landing accident. The grid spacing is 5°. Figure 128D is a detail of the mosaic including Vavilov crater. The images are of high quality, surpassing Lunar Orbiter coverage in some areas. This region was seen by Lunar Orbiter 5 only obliquely and very near the terminator, with some areas lost in shadow. Figure 128E depicts the area covered by Zond 6 images, according to an index map provided by MIIGAiK. Figure 128C covers a slightly smaller area. The terminator was near the center of the farside at the time, so topography was well defined in the left (western) half of the photographed area, and albedo was well seen in the right (eastern) half. All images are courtesy of MIIGAiK.

Rodionov, B. N., Isavnina, I. V., Avdeev, Yu. F., *et al.*, 1971. New data on the Moon's figure and relief based on results from the reduction of Zond 6 photographs. *Cosmic Research*, v. 9, no. 3, pp. 410-417.

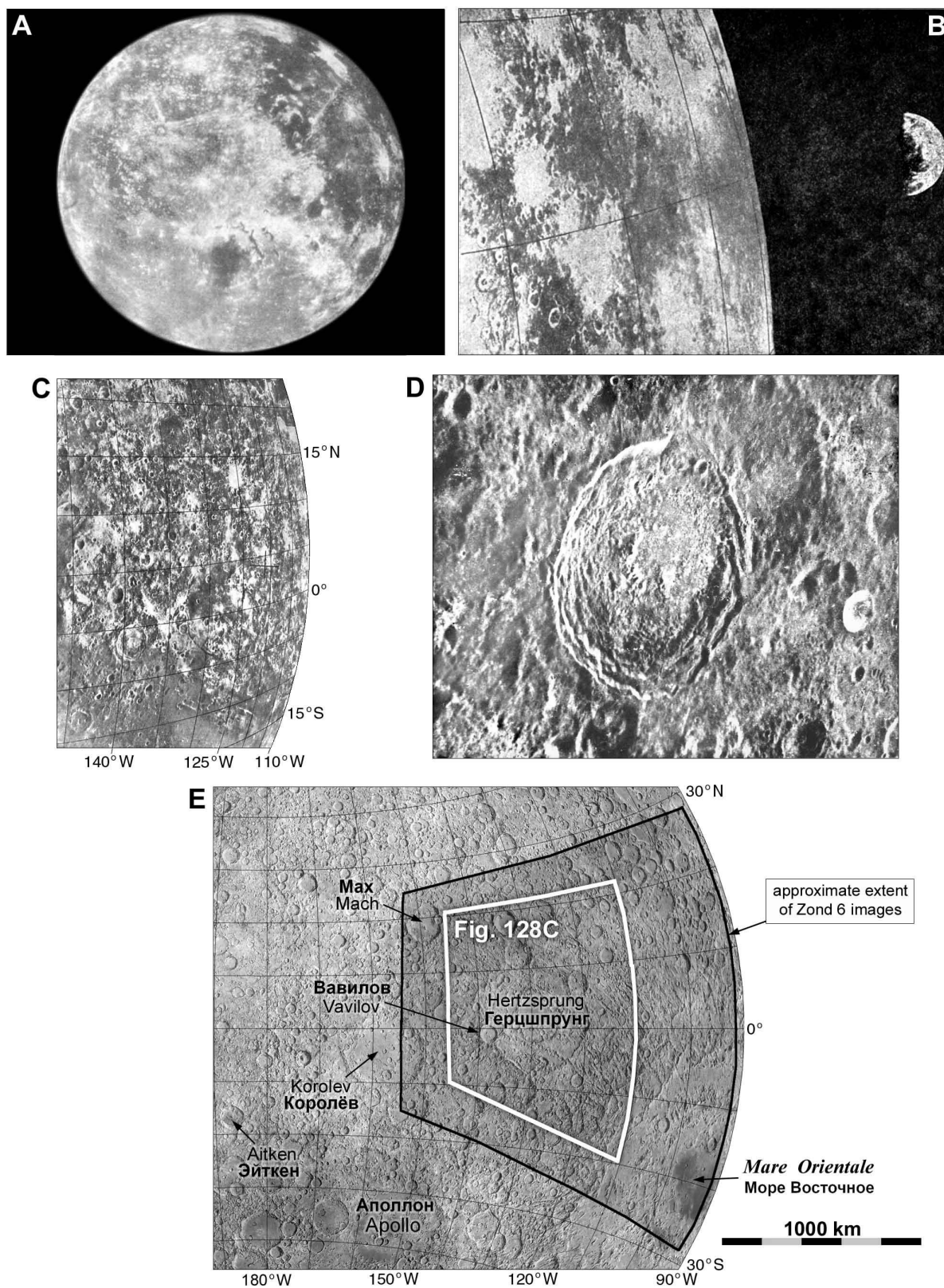


Figure 128. Zond 6 images. A: full phase image. B: the setting Earth. C: mosaic of high resolution coverage. D: Vavilov crater, 100 km diameter. E: Zond 6 photographic coverage. All images courtesy of MIIGAiK.



19 December 1968: Rover mission planning

A Bellcomm memo by Farouk El-Baz, dated 19 December 1968, described possible long range remote-controlled rover missions which Hal Masursky (USGS Flagstaff) had presented to the GLEP Site Selection Subgroup on November 13-14 at Menlo Park, California. The rover plans had been developed for the 'Flagstaff Group on Dual Mode Site Selection'. This group was considering combined robotic and human missions.

The rovers described here would land at points marked 1 in Figure 129A and be driven from Earth to the point marked 2 along each route. At that point they could rendezvous with the crew of a separate landing mission, possibly delivering samples collected along the route. If desired, the rover could then be driven remotely again to various alternate locations (3 in the map). Masursky preferred the routes which crossed Mare Serenitatis or Mare Imbrium so they could make geophysical measurements relating to the recently discovered 'mascons' (Figure 84C). Similar rover missions had been considered at the Santa Cruz meeting in 1967 (Figure 88). These routes ranged from about 1000 to 2000 km long.



1968: Hyginus mission

Kaplan (1968) described a mission to Hyginus as part of a study of the use of a Lunar Flying Unit (LFU). The study addressed problems such as lighting, visibility and line of sight communication applied to a potential Apollo site.

The Extended LM equipped with two LFUs would land north of the rille and west of the main crater, near the ALEO site in Figure 125. The landing site (Figure 129B) was at 8° 3' N, 6° 12' E on contemporary maps. Three science goals requiring LFU access were the main crater floor (point A at 7° 45' N, 6° 14' E), the floor of the rille (point B at 7° 57' N, 6° 2' E) and the plateau surface on the south side of the rille (point C at 7° 51' N, 5° 56' E). The LFUs would be powered using residual fuel from the ELM descent stage, with the longest flight done first and the second LFU standing by for a rescue flight if needed.

Point C, the plateau south of the rille, is at about the same level as the ELM, so no intermediate landing was required. This 10 km flight would be done first, and on the return flight the astronaut would examine the B region to help plan the last flight. Point A, 9 km from the ELM, would be the next target but it lies deep within Hyginus crater where line of sight communication with the ELM is impossible. The problem would be solved by setting up a relay station on the rim of the crater, but fuel reserves would not permit a landing on the way to A, so a separate trip would have to be made before the main flight. One astronaut would deploy the relay station and returns to the ELM to refuel and stand by for rescue as the second astronaut visited point A. Point B, the last LFU sortie target, would also need a relay station, but this short trip (5.8 km each way) could accommodate a landing on the rille edge to deploy the station.

Kaplan, M. H., 1968. *Mission Aspects of Lunar Flying Unit Design and Operation*. Bellcomm memorandum TM-68-2015-5 (NASA-CR-73508), 10 October 1968.



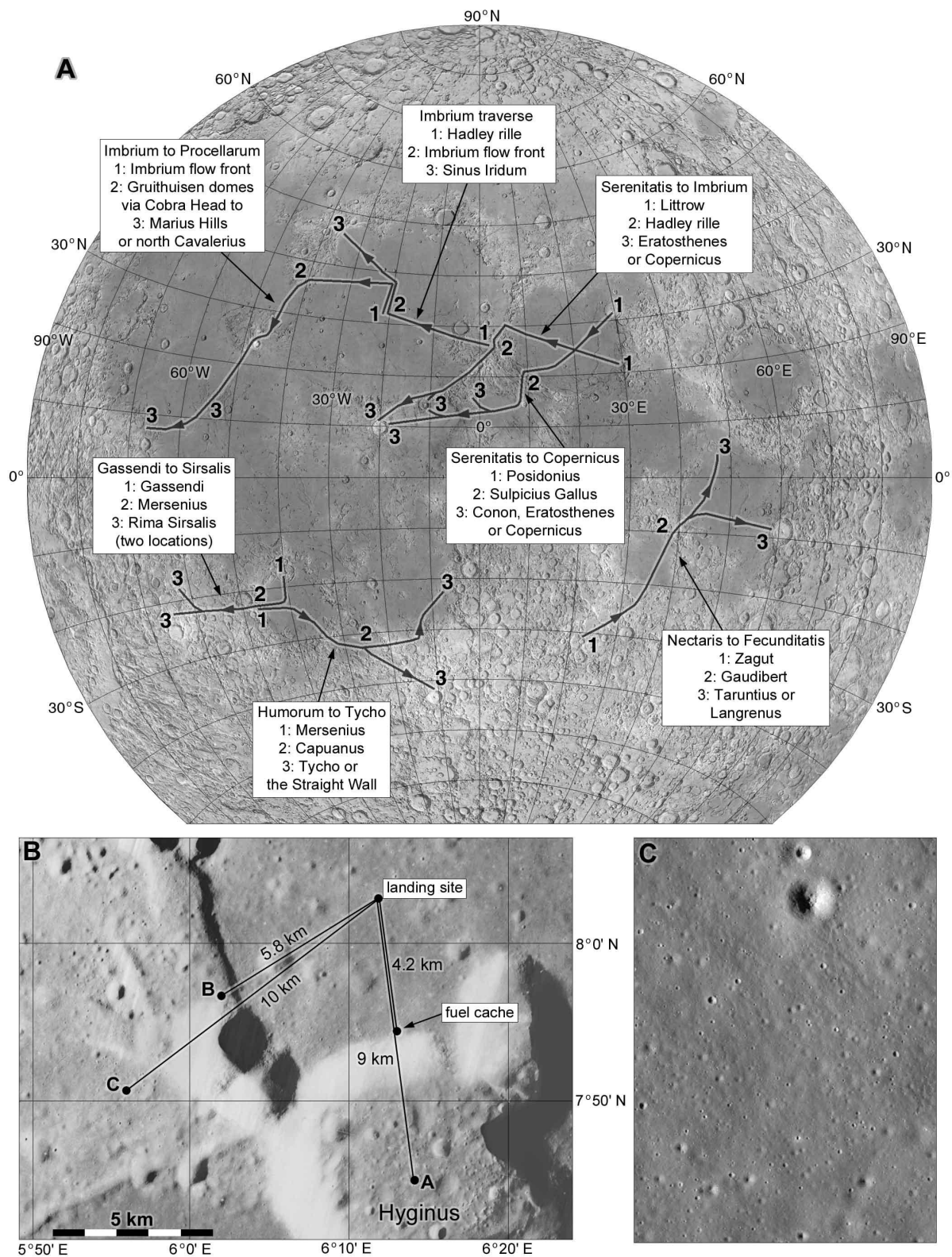


Figure 129: Flagstaff rover missions and Hyginus proposal from Kaplan (1968). A: rover route map. B: Hyginus mission area with flying routes. C: Hyginus landing site area.

21 December 1968: Apollo 8

Apollo 8 was the first human flight to the vicinity of the Moon. The 28817 kg Apollo Command/Service Module (CSM) was launched from the Kennedy Space Center at 12:51 UT on a Saturn 5 rocket, the first Saturn 5 launch with a crew. No lunar module was flown on this mission, but a 'test article' with the same mass was flown to fully test the Saturn systems.

The CSM and Saturn IVB (SIVB) upper stage entered a 191 by 183 km, 32.5° inclination parking orbit with a period of 88 minutes to check all spacecraft systems. At 15:42 UT the upper stage burned to place Apollo 8 on its translunar trajectory. The SIVB was later separated and passed the trailing edge (eastern limb) of the Moon to enter solar orbit. Lunar orbit insertion occurred at 09:59 UT on 24 December. The initial elliptical orbit was 311 by 111 km, with a 129 minute period, inclined 12° to the equator. After two revolutions the orbit was approximately circularised at 110 by 112 km with a 119 minute period for the remaining eight lunar orbits. Trans-Earth injection occurred at 06:10 UT on 25 December. The Command Module re-entered Earth's atmosphere and splashed down in the Pacific Ocean on 27 December at 15:52 UT, about 1600 km SSW of Hawaii (165° 1.2' W, 8° 7.5' N). The total flight time was 147 hours. The Apollo 8 Command Module is now in the Chicago Museum of Science and Industry.

The Apollo 8 crew were Frank Borman (Commander), James A. Lovell (Command Module Pilot) and William A. Anders (Lunar Module Pilot). Precursor flights (not including several launch vehicle tests) had been Apollo 4 (9 November 1967, the first full Saturn 5 launch with a Command Module test article), Apollo 5 (22 January 1968, the first test of the Lunar Module in Earth orbit, without a crew), Apollo 6 (4 April 1968, the final CSM test flight without a crew) and finally Apollo 7, launched on 11 October 1968, which tested the Apollo CSM in Earth orbit in a flight lasting 260 hours. Apollo 7's crew were Walter Schirra, Jr. (Commander), Donn F. Eisele (Command Module Pilot) and R. Walter Cunningham (Lunar Module Pilot). Apollo 7 splashed down in the Pacific Ocean on 22 October 1968.

The Apollo 8 astronauts undertook a program of photography of the lunar surface. The crew carried two 70-mm Hasselblad cameras and a 16-mm Maurer camera with various lenses, with a timer for stereo strip photography. The goals were to obtain improved coverage of parts of the farside at high resolution, to observe candidate Apollo landing sites and other targets of interest, and to record operational activities.

The astronauts took 588 photographs of the Moon as well as images of Earth and crew activities, obtaining seven 70-mm magazines and five 16-mm magazines of lunar photography (NASA, 1969). Most of the images were taken from low altitude and cover only the area under the spacecraft, along the orbit from the eastern (farside) terminator to the western (nearside) terminator. Other images taken to each side of the groundtrack show the surface obliquely, extending coverage out towards the horizon. Later Apollo missions produced many more of these side-looking views, but on Apollo 8 the crew, feeling overscheduled and suffering a lack of sleep, did not complete the full photographic program. After the trans-Earth injection (TEI) rocket firing to bring the spacecraft home, images of a broader area were taken from higher altitudes.

The areas covered by these images are shown in Figure 130. Here and in all subsequent Apollo image coverage maps the nearside is shown at top and the farside below. The high resolution photographic coverage runs from terminator to terminator under the orbiting spacecraft. The broad area seen in lower resolution views during the departure from the Moon is also shown. The Moon was not visible from Apollo trajectories during the initial approach.

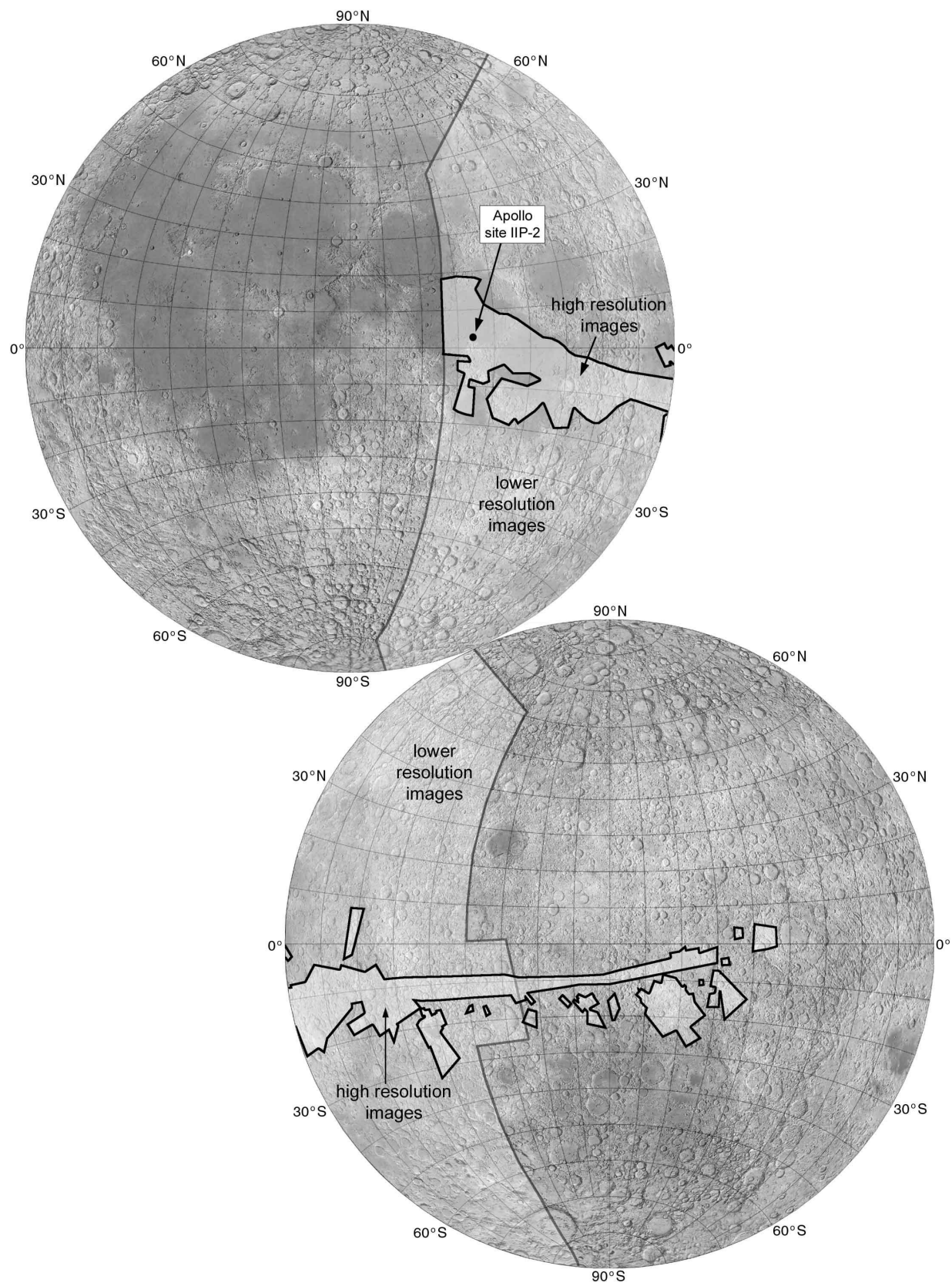


Figure 130. Apollo 8 photographic coverage.

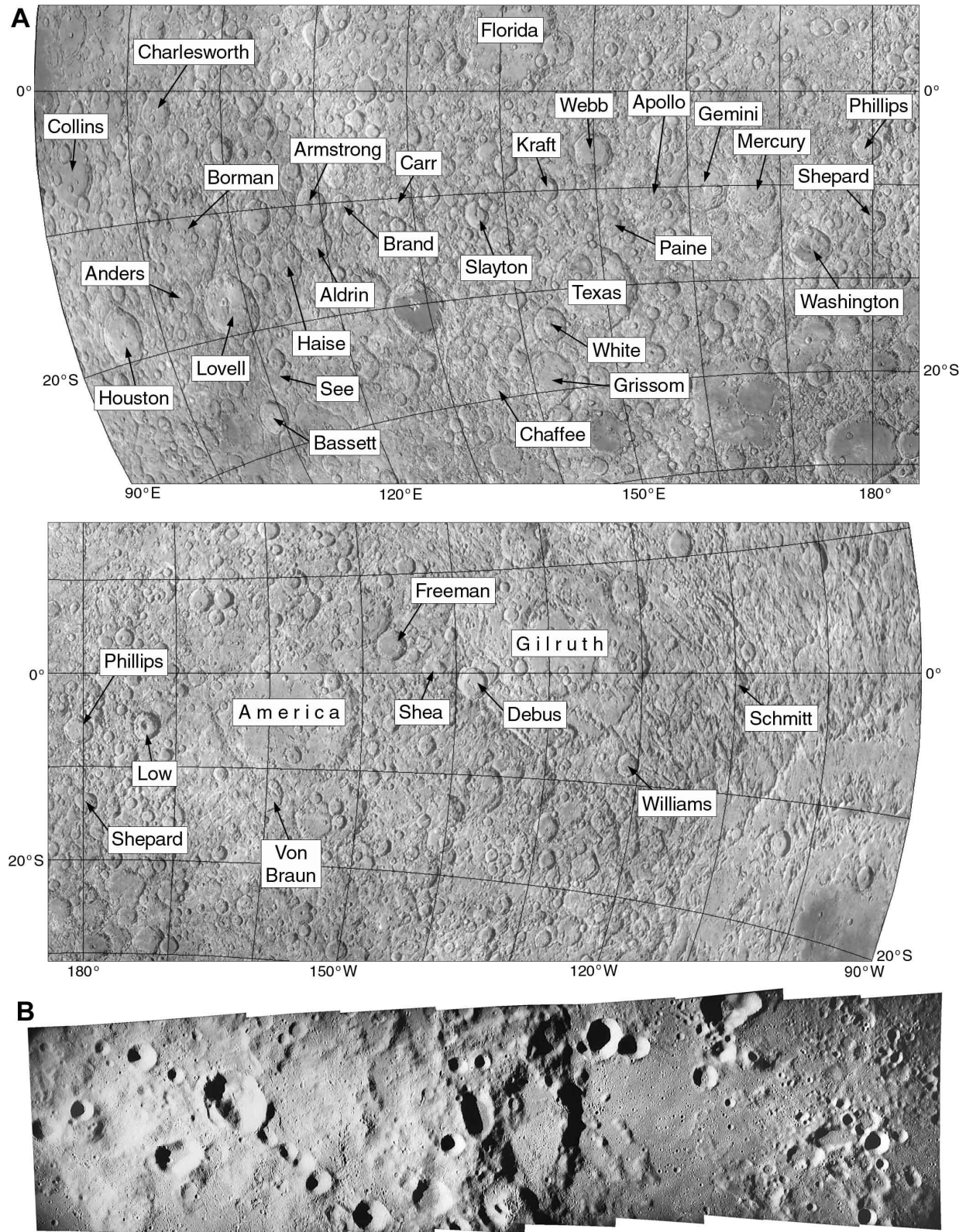


Figure 131. Apollo 8 mission. A: farside communication designators (unofficial names for crew reference purposes). B: Apollo 8 farside mosaic strip covering the large basin Korolev (right half) and adjacent highlands.

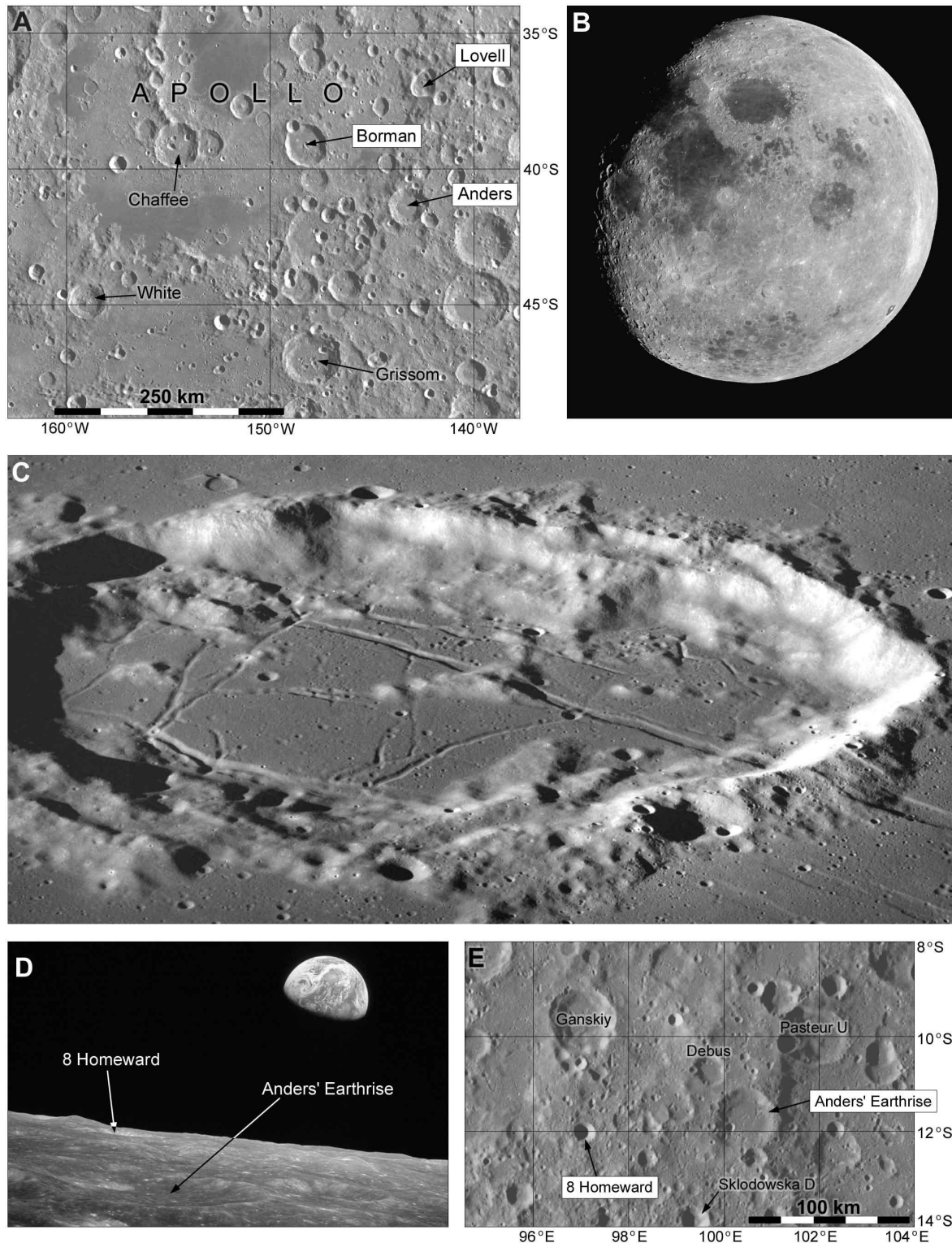


Figure 132. Apollo 8 mission and Soviet planning. A: craters named after Apollo 8 astronauts. B: Apollo 8 image AS08-14-2506 showing the eastern limb area and farside highlands, with Mare Crisium near the top and Mare Australe at bottom. C: Apollo 8 image AS08-13-2225 showing the crater Goclenius. D, E: Apollo 8 50th anniversary commemorative nomenclature. D is Apollo 8 image AS08-14-2383. E locates the two named craters.

Apollo site IIP-2 was one of the highest priority targets for photography, but few images showed the area and low light levels or glare interfered with viewing. Some oblique views of the landing area provided an astronaut's view of the approach, which might help with training. A particular highlight which received very wide publicity was the spectacular view of 'Earthrise' over the lunar horizon as the spacecraft approached the limb over Mare Smythii (Figure 132D). Apollo spacecraft orbited from east to west over the lunar surface and saw Earthrise over the eastern limb. The first three Lunar Orbiters had travelled in the opposite direction and could view Earth setting in the same region.

The only official names on the farside at this time were some of those associated with Luna 3 (Figure 11). Names on Zond 3 Soviet charts (Figure 37) had not yet been adopted by the International Astronomical Union. Apollo planners, needing feature names for reference during the flight, annotated a copy of the Apollo Lunar Flight Chart with the unofficial 'Farside Communications Designators' shown in Figure 131A. They occupy only the region under the Apollo 8 orbital groundtrack. They were never considered or proposed as official names, but some made their way into communications and reports. Most names commemorate people associated with NASA and Apollo, and some were later adopted for use elsewhere (Figures 132A, 141). Figure 131B is a mosaic of Apollo 8 images showing the floor of the 450 km diameter basin Korolev and the highlands to the west. The mosaic covers a region about 300 km long.

The Apollo basin and its surroundings on the farside are mapped in Figure 132A. Craters named after the Apollo 8 crew are labelled in white boxes. Craters named after the Apollo 1 crew (Figure 74B) are also indicated. Later, other craters in this area were named after the 14 astronauts who died in the two Space Shuttle accidents. Soviet cosmonauts had been commemorated around Mare Moscovense (Figure 74A).

Figure 132B is a view of the Moon from the returning spacecraft (Apollo 8 image AS08-14-2506). The bright area near the limb at extreme right is the ray system interpreted in the Luna 3 maps (Figure 11) as the Soviet Mountains. Figure 132C is an oblique image of the crater Goclenius at 10° S, 45° E, between Mare Fecunditatis and Mare Tranquillitatis, with its prominent fractured floor. Figure 132D is the Earthrise image taken by Anders on 24 December 1968, and two commemorative names in the same area are shown in Figure 132E. The names were assigned in October 2018 as the 50th anniversary of the flight approached. '8 Homeward' was previously known as Ganskiy M, and 'Anders Earthrise' was formerly Pasteur T.

NASA, 1969. *Analysis of Apollo 8 Photography and Visual Observations* (NASA SP-201). Washington, D.C.: Scientific and Technical Information Division, National Aeronautics and Space Administration.



1968: Soviet landing site planning

Landing site studies were conducted at the Institute for Cosmic Research (IKI) in Moscow in 1968 and 1969, in preparation for possible cosmonaut landings in the coming year. This work involved assessing candidate areas for smoothness and safety, as in the United States. No Luna spacecraft had returned images suitable for site selection except Luna 12 (Figure 55), and its images were far too limited in coverage to be useful here. Much of this analysis was clearly based on Lunar Orbiter images, many of which had been published and were widely available. It follows that the sites were limited to Lunar Orbiter imaging targets. Photographic prints or the U.S. Army and Air Force photomaps derived from them may also have been obtained, but the details have never been made clear.

Analysis focussed on three broad equatorial areas in the western, central and eastern maria, just as in the United States. Stooke (2007) speculated that these corresponded to Oceanus Procellarum, Sinus Medii and Mare Fecunditatis and noted that actual sites were presumably limited to Lunar Orbiter sites in those areas. The Sinus Medii area was rejected for being too rough, leaving just the eastern and western areas in consideration. (A. T. Basilevsky, personal communication, 2003). A presentation by Basilevsky at the Brown-Vernadsky

Microsymposium in The Woodlands, Texas on 16 March 2014 illustrated four sites corresponding to sites IIP-6, IIP-8, IIP-11 and IIP-13 as the potential landing areas (Figure 133A). In the spring of 2016, 2017 and 2018 Basilevsky taught a short course in Planetary Geology at the Macau University of Science and Technology, Macau, China, and a presentation from that class showed these sites labelled α , β , γ and δ (from west to east).

Brian Harvey suggested that an earlier set of potential sites from about the time of Luna 12 included Aristarchus, Alphonsus, Sinus Medii and Mare Tranquillitatis (not the Apollo 11 area). The inclusion of Alphonsus reflected an obvious desire to follow up Kozyrev's observations (Figure 28). Luna 12 took images of the Aristarchus region (Figure 55). These sites were changed by 1968 because orbital plane considerations required the site to be close to the equator, as were the early Apollo sites. No information has been released concerning specific landing targets within these larger Lunar Orbiter sites.

Stooke, P. J., 2007. *The International Atlas of Lunar Exploration*. Cambridge: Cambridge University Press.



1968: Advanced Mission Planning

As the first Apollo landing neared, ever more dramatic future activities were proposed. A late Apollo mission was considered for the interior of the Orientale basin, where landing during a favourable libration would permit direct communication. The landing area would be southwest of Kopff crater. Mobility would be limited, but sufficient to sample the mare material, crater rays from Maander crater, the rim of Kopff (possibly a volcanic caldera rather than an impact crater), and pre-mare basin floor materials. A more advanced post-Apollo option would be a long rover traverse similar to those discussed at Falmouth and Santa Cruz (Figures 32, 88). A 400 km traverse with astronauts was envisaged (Ulrich, 1968), including LFU flights into the two prominent craters Kopff and Maander. The crew traverse would be preceded and followed by remotely controlled traverses of the rover (Figure 133B). This mission concept was also discussed at the GLEP meeting of 04 June 1968.

Ulrich, G. E., 1968. Advanced systems traverse research project report. *Interagency Report: Astrogeology 7*, U. S. Geological Survey, July 1968.



20 January 1969: Soyuz circumlunar mission

This Soviet test of Soyuz lunar hardware was aborted when the Proton launcher's second stage engine failed 500 seconds after launch. The capsule abort system carried the Soyuz to a safe landing in Mongolia. Further tests of this system were now postponed so that all efforts could be devoted to testing the giant N1 rocket and flying a successful robotic lunar soil sample return mission before the first Apollo landing. This now seemed to be the best remaining way for the Soviet Union to respond to Apollo, claiming as it did so that the U. S. approach was unnecessarily risky and expensive compared with robotic missions.



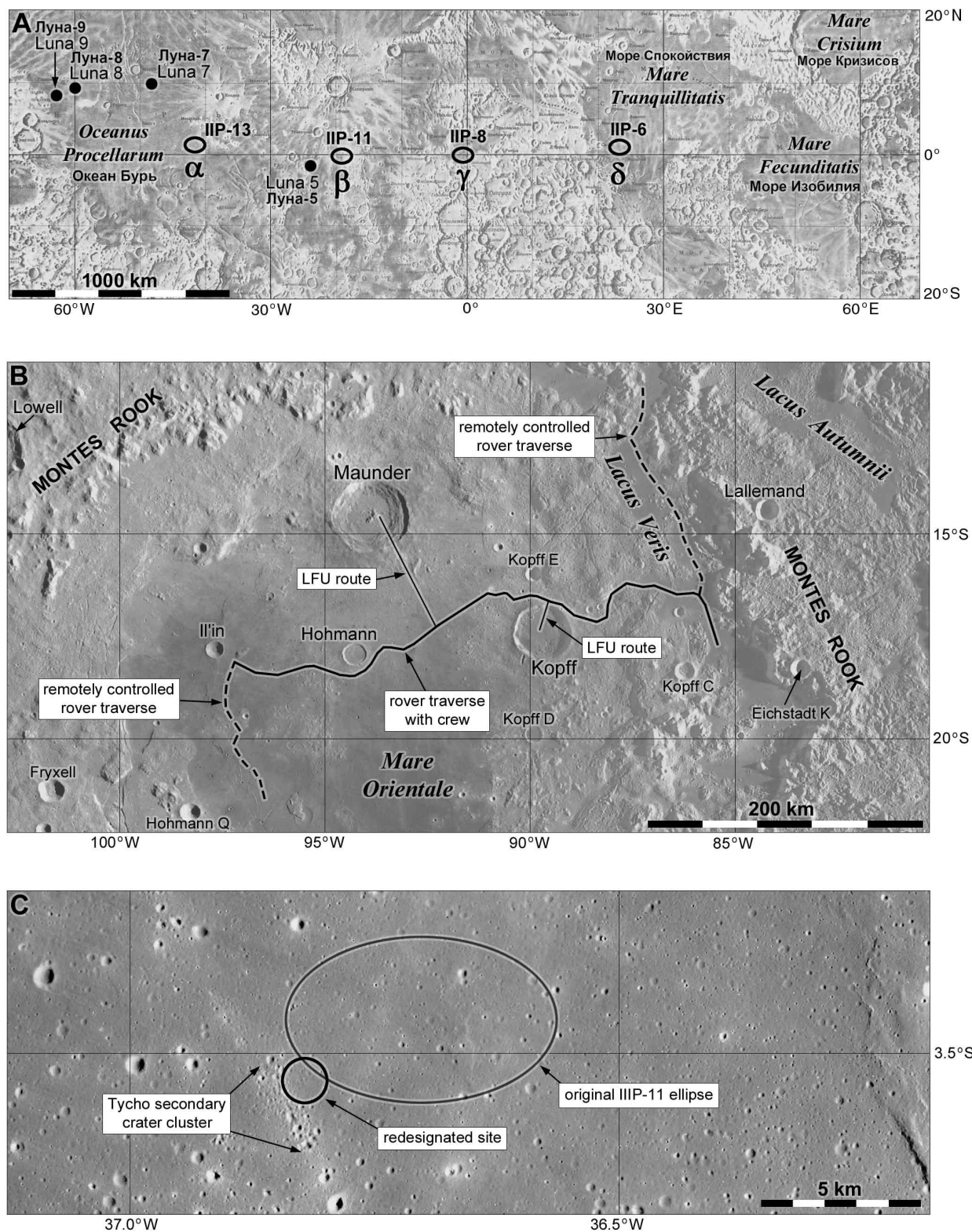


Figure 133. Soviet and NASA mission planning. A: Soviet cosmonaut landing areas plotted on a contemporary Russian lunar map. Four ellipses mark the Lunar Orbiter 2 imaging targets which were considered for landings by cosmonauts. B: Proposed Orientale basin traverse (Ulrich, 1968). C: Redesignated site IIP-11R, within walking distance of a secondary crater cluster, possibly from Tycho.

19 February 1969: Luna 1969A

A Soviet rover similar to Lunokhod 1 was destroyed 40 seconds after its launch from Baikonur at 09:48 local time. A booster engine failure caused the vehicle to crash 15 km from the launch pad, scattering radioactive debris from its internal heat source. It has been suggested that the rover was to land at one of the potential cosmonaut landing sites (Figure 132D), to find an area free of obstacles and to deploy a radio beacon. If the N-1 launch of 21 February had been successful there might have been an attempt to receive transmissions from that beacon during lunar orbit tests of the Soyuz spacecraft. The lunar phase at the expected landing date (26 February) suggests this rover would have landed at the Mare Tranquillitatis or Sinus Medii sites. However, this may be a repetition of one of the original rationales for rover missions rather than a plan for this particular flight, and another Russian source suggests that this rover was to be sent to Le Monnier, the target for Lunokhod 2 in 1973. The lunar phase at launch supports that assertion. Plans announced on 10 June 1969 by the VPK Military-Industrial Commission called for two more rovers to be launched on 22 October and 21 November, and five soil sampling and return missions like the future Luna 16 on 14 June, 13 and 28 July, 25 August and 25 September, in a last desperate attempt to outflank Apollo.



21 February 1969: First N-1 launch

This was the Soviet Union's first launch of the new N-1 booster. The rocket lifted off from Baikonur at 09:18 UT, but several seconds after launch two engines shut down. The remaining engines compensated, but about a minute later at an altitude of 30 km another failure caused the remaining engines to shut down. The N-1 crashed about 50 km from the launch pad. The spacecraft payload was a Soyuz/Zond crew module, to be flown without a crew into lunar orbit for automated photography of possible landing sites. A dummy lander was carried for realistic system mass tests. The capsule was lifted clear by its escape system and landed 35 km from the pad.



27 March 1969: Group for Lunar Exploration Planning

At this meeting GLEP considered various alternatives for the second landing, as summarized in Table 42. The relocated (or redesignated) site IIIP-11R considered here was not the circle shown in Figure 122C, but a new location on the southwestern edge of the old IIIP-11 ellipse adjacent to a chain of 100 m diameter craters (Figure 133C). These were interpreted as secondary craters, formed by debris thrown out by a large distant impact. They lay on an outer part of the Tycho ray system and thus gave an opportunity to study ray material and possibly to gather some Tycho ejecta. This might allow the Tycho impact to be dated. The GLEP illustration did not show the enlarged IIIP-11 ellipse (Figure 123E), reverting instead to the original ellipse shown in Figure 105.

GLEP also outlined expectations for improved landing accuracy and surface mobility. For the first missions, the landing could occur anywhere in a roughly 15 by 5 km ellipse (Figure 123), with an exploration range of only 1 km from the LM. This was expected to improve to a landing accuracy of 1 km and an exploration range of 5 km.

Table 42. GLEP second mission priorities, 27 March 1969.

A. Considering prime sites only.					
First landing:	IIP-2	IIP-6	IIP-8	IIIP-11	IIP-13
Second landing:					
IIP-2	X	2	2	3	3
IIP-6	2	X	-	1	1
IIP-8	3	-	X	2	2
IIIP-11	1b	1b	1b	X	-
IIP-13	1a	1a	1a	-	X
B. Considering relocated sites.					
First landing:	IIP-2	IIP-6	IIP-8	IIIP-11	IIP-13
Second landing:					
IIP-2	X	2	2	3	3
IIP-6	2	X	-	1	1
IIP-8R	3	-	X	2	2
IIIP-11R	1b	1b	1b	5	4
IIIP-12R	1a	1a	1a	4	5
X: not considered for the second landing because (in this plan) the site had already been visited. R: relocated site. A dash indicates that this site would not be considered for the second landing. Sites 1a and 1b were both high priority, with 1a slightly preferred over 1b. Site IIIP-12R is the Flamsteed hill location (Figure 112D).					

Just before this GLEP meeting Noel Hinners (Bellcomm) had been considering the retention of multiple landing sites per launch (Hinners, 1969). Each landing mission had a prime landing site and one or two backup sites (two for Apollo 11, one each for the next two missions), to be used if the launch was delayed. Backup sites were always further to the west, following the morning terminator so that the landing always occurred not long after sunrise, with long shadows to help define topography as the crew sought a safe location. GLEP was now considering later landings at diverse sites, and Hinners concluded that backup sites could be considered but might be more constrained. Some landings might carry site-specific payloads which would be wasted at a backup site. Multiple sites also increased demands on the crew including extra training.

Hinners was also concerned about the construction of geophysical networks on the surface. The interval between early Apollo launches was about 4 months, but the expected lifetime of instruments on the surface was less than two years. Thus, a given three node network configuration taking a year to construct might operate for less than a year before its older components failed. Sites would have to be chosen to maintain good network configurations as sites failed or were added. Hinners illustrated several possible networks. Littrow, Marius and Tycho made an excellent network, a widely spaced triangle spanning much of the nearside. Other configurations such as Littrow, Censorinus and Fra Mauro or (even worse) Hyginus, Copernicus and Schröter's Valley were smaller, narrower triangles which would less easily resolve seismic event locations around the Moon.

Hinners, N. W., 1969. *Continued use of multiple sites per launch opportunity in the lunar exploration program.* Bellcomm memorandum, 4 March 1969. NASA-CR-106422.



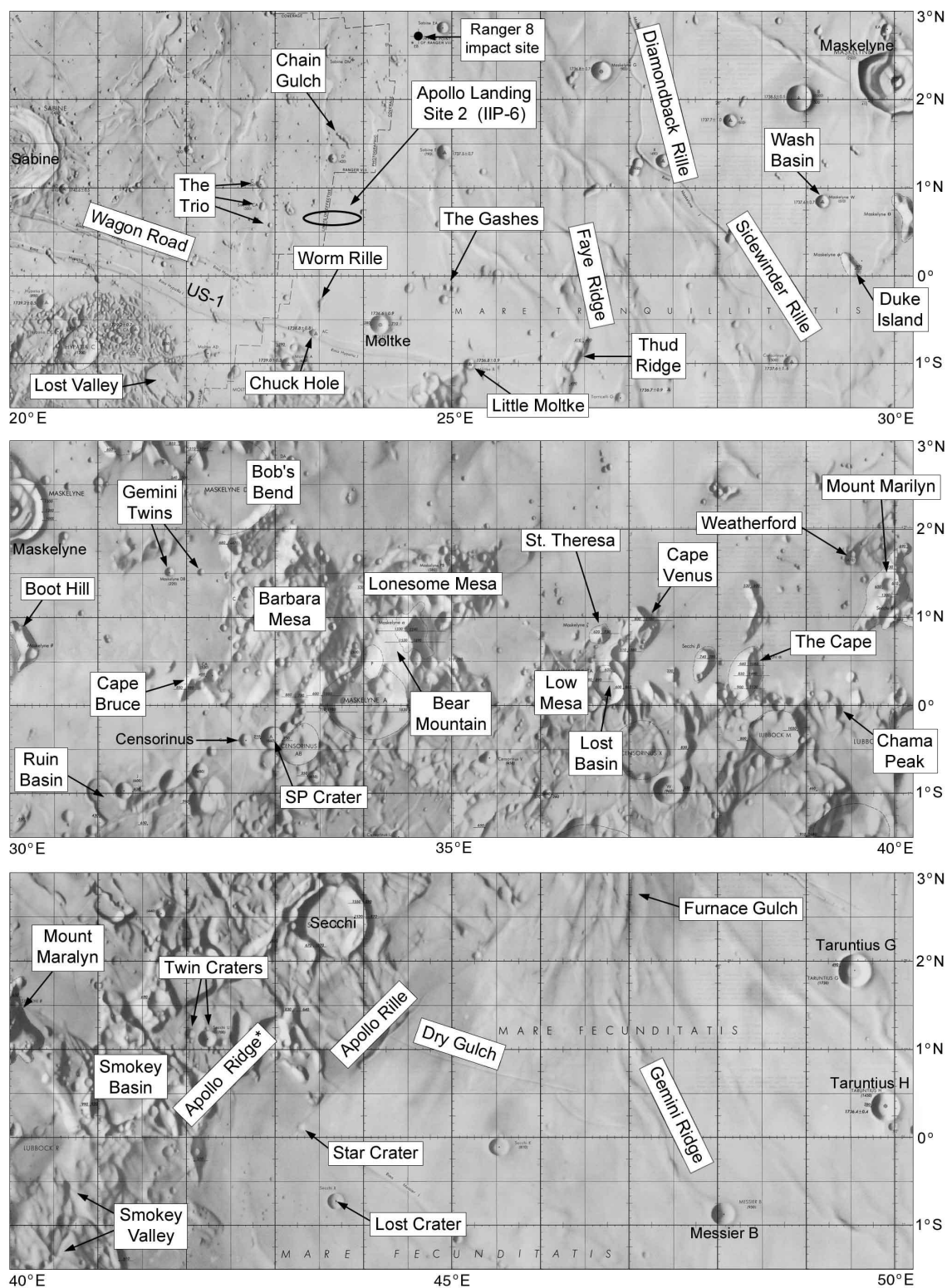


Figure 134. Informal feature names used by the crew of Apollo 10 (many were later made official). The base map is a composite of ACIC AIC charts 60C, 61C, 61D, 78B, 79A and 79B. For scale, 1° spans 30 km. * see note in text regarding Apollo Ridge.

15 April 1969: Luna 1969B

This mission was the first attempted flight of a sophisticated new lander intended to return lunar regolith samples to Earth, the Soviet Union's last chance to beat Apollo to this important lunar goal. The target area was in the eastern maria, probably near the future Luna 16 landing site. The spacecraft was essentially identical to Luna 15 and 16. It was lost in an explosion on the launch pad at Baikonur.



18 May 1969: Apollo 10

Apollo 10 was a 'dress rehearsal' for the first lunar landing mission. A precursor to this flight was Apollo 9, launched on 3 March 1969, which tested the full Apollo system including the Lunar Module (LM) in Earth orbit in a flight lasting 241 hours. Apollo 9's crew were James McDivitt (Commander), David Scott (Command Module Pilot) and Russell Schweickart (Lunar Module Pilot).

The crew for Apollo 10 was Thomas Stafford (Commander), John Young (Command Module Pilot) and Eugene Cernan (Lunar Module Pilot). Stafford had flown previously on Gemini 6 and Gemini 9. Young had flown on Gemini 3 and Gemini 10, and would fly later on Apollo 16. Cernan had flown on Gemini 3 and later flew on Apollo 17. Apollo 10 orbited the Moon, testing the LM and the entire flight profile including the untested lunar orbit rendezvous upon which Apollo depended, omitting only the landing itself. The CSM call sign was "Charlie Brown", the LM was called "Snoopy".

The fully fuelled LM mass was 13,941 kg. This unique lander consisted of a lower 'descent' stage with the main landing engine, four legs spanning 10 metres diagonally, and equipment storage bays, and an upper 'ascent' stage housing a smaller engine for the lunar take-off and return to orbit, plus the crew cabin. Apollo 10 camera equipment consisted of two 70-mm Hasselblad cameras, a telephoto lens for close-up images, and two 16-mm automated sequence cameras, one in the CSM and one in the LM (NASA, 1971).

After launch at 16:49 UT (just before midnight EST on 17 May, local time) the spacecraft entered a 190 by 184 km parking orbit. After 1.5 orbits at 19:28 UT the SIVB upper stage burned for trans-lunar injection (TLI). The CSM separated from the S-IVB, turned to face it, and docked with the LM at 20:07 UT. Apollo 10 entered a 316 by 110 km lunar orbit on 21 May at 20:45 UT, and later circularised the orbit at 114 by 109 km. On 22 May Stafford and Cernan detached the LM from the CSM at 19:37 UT, and dropped its orbital low point to 14 km over the nearside to make low passes over landing sites IIP-2 and IIP-6. All LM and ground systems needed for a landing were tested successfully. Close-up photographs of the Moon's surface including the landing sites were taken (Figure 133C), though the best images of site IIP-6 were lost when a camera jammed.

The LM descent stage was jettisoned into low lunar orbit, and ultimately would have crashed on the lunar surface within a few degrees of the equator, but its location is unknown. The LM rendezvoused with the CSM and docked 8 hours after separation at 03:22 UT on 23 May. Several hours later the LM ascent stage engine was burned to depletion, placing the vehicle in a solar orbit to prevent it interfering with later missions. In 2018 a small near-Earth asteroid called 2018 AV2 was discovered at Mt. Lemmon Observatory, in a 382 day solar orbit. It is thought to be Snoopy's ascent stage, and it will pass about 6 million km from Earth on 10 July 2037.

On 24 May at 10:25 UT, after 31 lunar orbits, the CSM rockets burned to leave lunar orbit and return to Earth. The Command and Service modules separated at 16:22 UT on 26 May and Apollo 10 splashed down safely in the Pacific Ocean at 16:52 UT, ending a 192 hour mission. Splashdown occurred at 15° 2' S, 164° 39' W, 600 km east of Samoa and 5.5 km from the USS Princeton recovery ship. The Apollo 10 CSM is currently on display in the Science Museum in London, U. K.

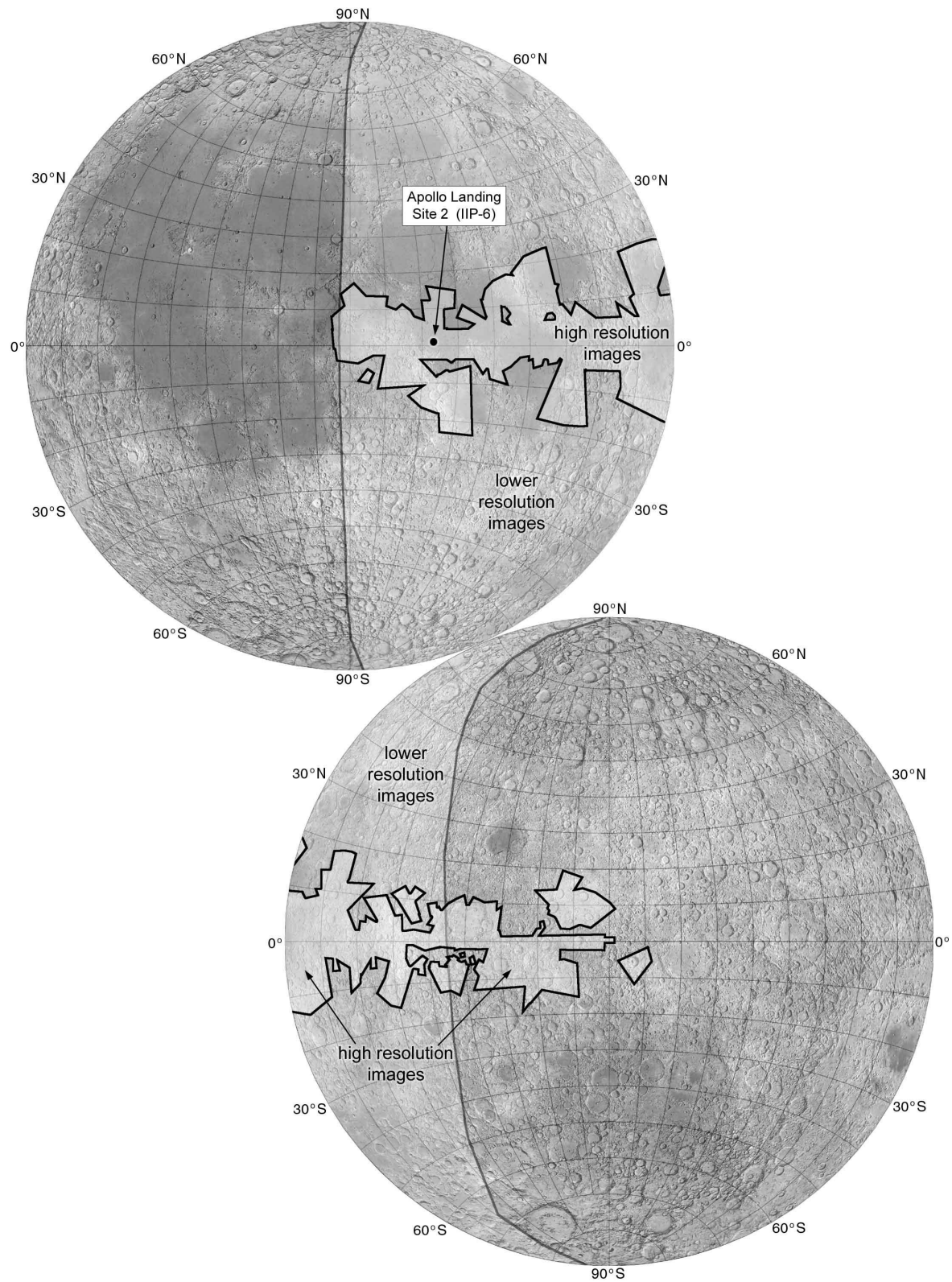


Figure 135. Apollo 10 photographic coverage.

By the time of Apollo 10 the informal farside ‘communication designators’ (Figure 131A) had been replaced by a more acceptable temporary system of numerical crater designations. Large craters and basins were identified by roman numerals, smaller craters by numbers. Informal names were now applied to landmarks on the approach to the Apollo 11 prime landing site (ALS-2). Most names commemorate people associated with the astronauts (e.g. Mt. Marilyn refers to Apollo 8 astronaut James Lovell’s wife; Weatherford was astronaut Stafford’s Oklahoma birthplace, and coincidentally the name of a historic hotel in Flagstaff). Some are whimsically descriptive. Star Crater refers to a small bright-rayed crater at 0.05° N, 43.24° E. SP Crater refers to a volcanic crater near Flagstaff. Some of these names are found in news reports of the period. This full set of names (Figure 134) is taken from a hand-lettered copy of the ACIC Apollo 10 LM Descent Monitoring Chart, edition 1, 30 April 1969, preserved at the Lunar and Planetary Institute in Clear Lake, Texas. None of the informal names were intended to become official, though most of them were accepted later. These names were also printed on the Apollo 11 Descent Monitoring Chart, with several changes. A small crater on the rim of Sabine was named Dark Crater, Star Crater was omitted, and Apollo Ridge was named Twin Crater Ridge. Twin Craters was dropped as a name, and the name Apollo Ridge was moved slightly east and had no obvious link to any specific feature.

Apollo 10 orbital photographic coverage is plotted in Figure 135. High resolution images were made along the equator and out towards the horizon north and south of the groundtrack. After the TEI (trans-Earth injection) burn on the return leg of the journey, high altitude images covered the illuminated part of the near side and eastern limb at lower resolution.

NASA, 1971. *Analysis of Apollo 10 Photography and Visual Observations* (NASA SP-232). Washington, D.C.: Scientific and Technical Information Division, National Aeronautics and Space Administration.



1969: Advanced Apollo Planning

Mission planners continued to propose extravagant future missions, including a complex five day exploration of the Marius Hills site (Figure 136) proposed by Ellston and Willingham (1969). This plan shares some features with that shown in Figure 121 but provides for an even more detailed investigation of the geology and geophysics of this complex site. The mission would make use of an Extended Lunar Module (ELM), an enhanced lander capable of supporting longer surface stays. Eight rover traverses would fan out among the volcanic hills and flows. Three LFU sorties from the ELM would emplace communication relays on two hills and visit six locations for sampling and instrument readings.

An ALSEP instrument package would be deployed on the surface north of the ELM. Three arrays of geophones would be set out to measure subsurface structure, one with 8 and two with 3 geophones. The 8-geophone array was to be set out across a valley thought to mark a deep fracture. Explosive charges would be set out for this active seismic experiment and set off by control from Earth after the astronauts had left the surface. This experiment was eventually flown on Apollo 17. Gravity and heat flow measurements would be made at many locations, as shown in Figure 136. Despite the scientific importance of this site, it was never visited by Apollo astronauts.

Elston, D. P. and Willingham, C. R., 1969. Five-day mission plan to investigate the geology of the Marius Hills region of the Moon. *Interagency Report: Astrogeology 14*, U. S. Geological Survey, April 1969.



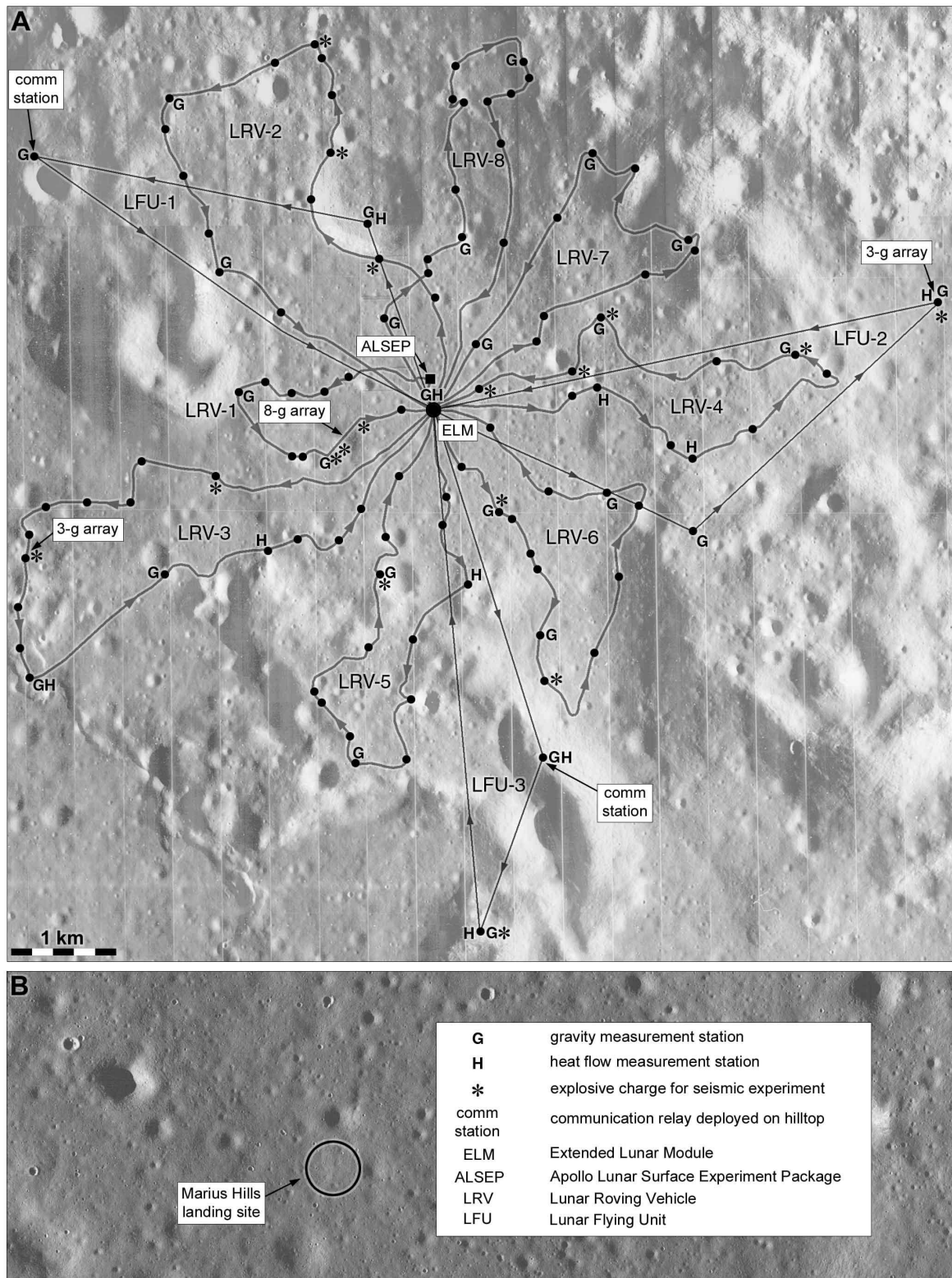


Figure 136: Marius Hills mission plan from Ellston and Willingham (1969). A: exploration scheme. B: landing site and legend for main map.

03 June 1969: Apollo Site Selection Board

Until this meeting the candidate Apollo sites had been known by their Lunar Orbiter designations (IIP-12 and so on). At this meeting ASSB officially renamed the five Set C sites (Figure 104) by numbering them 1 to 5 from east to west, so IIP-2 became Apollo Landing Site (ALS) 1 and IIP-12 became ALS 5 or Site 5 (Figure 137A). Redesignated ('biased') sites were labelled 'R', so the site shown in Figure 133C was now Site 4R. The five Surveyor sites were also considered viable targets and were named S-I, S-III, S-V and so on. S-I was also referred to as Site 6 and S-III was Site 7. The Flamsteed ring site (Figure 112D) was now 6R.

The discussion then turned to plans for landings after the first. One set of alternatives for the early landings was presented, allowing more conservative or aggressive approaches to planning as circumstances permitted (Table 43).

Table 43. Early Apollo landing site options.			
First landing	Sites 1, 2, 3, 4 or 5 (sites 2, 3 and 5 preferred)		
Second landing	Conservative approach		Aggressive approach
	1, 2, 3, 4 or 5		Include relocated sites: 1, 2, 3R, 4R, 6R
Third landing	Conservative approach	Intermediate approach	Aggressive approach
	Include relocated sites: 1, 2, 3R, 4R, 6R	Exploration sites in Apollo Zone: Censorinus, Fra Mauro	Exploration sites outside Apollo Zone: Tycho rim, Littrow

MSC proposed that if Apollo 11 failed to achieve the first landing, Sites 2, 3 and 5 remain the targets for Apollo 12, but if Apollo 11 landed at sites 2 or 3 then the S-III and S-I western Surveyor sites be used for Apollo 12. Landings would be targeted 300 m east and 150 m north of the landed Surveyor. ASSB chairman Gen. Sam Phillips rejected the Surveyor sites (the required pinpoint landing capability had not yet been demonstrated, and S-I was too far west, having no recycle option) and suggested Sites 2, 3, 5, Hipparchus or Fra Mauro for Apollo 12. MSC considered both Fra Mauro and Hipparchus unacceptable.

Benjamin Milwitzky of the Lunar Exploration Office, formerly Program Manager for Surveyor, promoted the Surveyor sites for the following reasons: the return of Surveyor parts and samples examined by the Alpha Scattering Instrument would give useful engineering information on the effects of long-term exposure to the lunar environment, and help verify the ASI results. Goals at each site are listed in Table 44.

Planners expected that each Apollo flight would provide photography of potential future sites. At this ASSB meeting plans were presented for photography of highland sites in the Apollo Zone from the CSM in lunar orbit during Apollo missions 10 and 11 (Figure 137B). They had already been put in place for Apollo 10, and would now be continued for Apollo 11. Sampling a highland site was scientifically important since highlands occupy most of the lunar surface, but in the end these sites in the Apollo zone were not visited. Highland samples were collected later at the Apollo 15, 16 and 17 sites well outside the narrow equatorial zone.

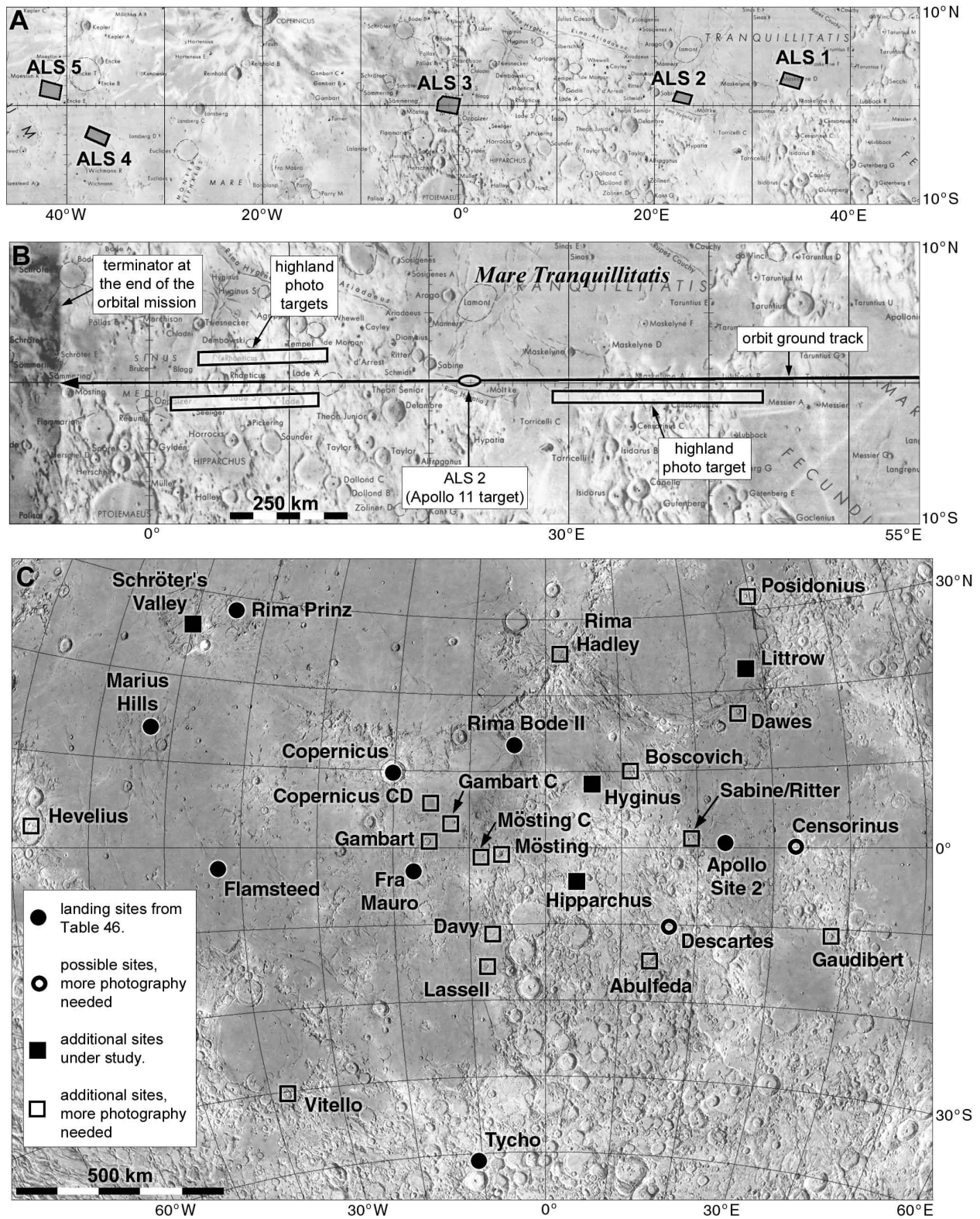


Figure 137. Apollo planning. A: the five sites (Set C) from which the Apollo 11 landing site would be chosen. B: Apollo 10 and 11 highland photography targets. C: Apollo sites from the 10 July 1969 ASSB meeting.

Table 44. Scientific goals of Apollo landings at Surveyor sites.	
Surveyor 1	Investigate and sample block field several hundred meters south of Surveyor and fresh crater east of Surveyor; return specified rocks; examine footpad and 'crushable block' shock absorber imprints in soil for mechanical properties of soil.
Surveyor 3	Return specified rocks; examine footpad imprints for erosion effects; examine trenches; examine spacecraft parts for changes; look for evidence of downslope transport of regolith.
Surveyor 5	Return samples analysed by ASI; see if Surveyor has shifted downhill; sample blocks on crater rim 200 m north of Surveyor; return specified rocks.
Surveyor 6	Examine wrinkle ridge and nearby craters; return samples analysed by ASI; photograph magnets carried by spacecraft and return any magnetic material adhering to them; examine pre- and post-hop footpad imprints and vernier blast disturbances.
Surveyor 7	Return specified rocks, including from rock-filled crater near Surveyor; return samples analysed by ASI; examine trenches for erosion or slumping; return or examine magnets and mirrors; sample the 'lake', ridges and apparent flows northeast of Surveyor.



14 June 1969: Luna 1969C

This mission was another attempt to obtain a soil sample from the eastern maria, probably from a site near the future Luna 16 landing site. The booster placed the spacecraft and upper stage in a parking orbit, but the upper stage suffered a failure in its control system and failed to ignite properly.



3 July 1969: Second N-1 launch

This mission was similar in its intent to the first launch on 21 February. It would have carried the Soyuz/Zond crew module, without a crew, into lunar orbit for automated photography of possible landing sites. A dummy lander was also to be carried for realistic system mass tests. Launch on the new N-1 booster from Baikonur was at 20:19 UT, but only a few seconds later debris in a fuel line caused an explosion in an engine pump. The engines shut down and the massive vehicle fell back onto the launch pad, causing very serious damage. The Soyuz capsule was lifted clear by its escape system and landed 1 km away.



10 July 1969: Apollo Site Selection Board

At this meeting, deliberations by the Group for Lunar Exploration Planning (GLEP) Site Selection Subgroup were presented and evaluated. The Subgroup had met on 17 June at the request of Sam Phillips to consider the scientific goals of lunar exploration and to propose a sequence of landings to address those goals. They worked with a list of

22 Set B sites (Table 45), differing in many details from the ASSB version of Set B (Table 41). From it they identified ten sites which might provide the necessary results and ordered them in a sequence (Table 46) which matched expectations of growing mission capability and maximum scientific return.

Widely separated sites were needed to ensure good geophysical data from deployed instrument packages. The Surveyor 3 site was not included in this GLEP sequence, as discussed below. ASSB, however, reinstated it for consideration for Apollo 12, and rejected Hipparchus and Fra Mauro for that mission. Descartes (later the Apollo 16 site) was also being considered at this time for its expected highland volcanic materials. Table 46 shows the GLEP recommended sequence as well as the modified sequence agreed to by ASSB at this meeting.

Farouk El-Baz (Bellcomm) described the sampling goals for these ten missions. They were the older (western) and younger (eastern) mare materials, broad deposits around mare basins, impact craters in both mare and highland areas, volcanic features in both types of area, and any features which might point to processes other than impact and volcanism. The ten proposed sites were related to these sampling goals. ASSB approved the ten sites for planning purposes.

One serious problem was that many of these sites would need additional photography for planning and certification. Apollo 10 photography was adequate for landing site studies, and GLEP now pointed out that photography during early landing missions could be used for later site studies if planned properly, a process which became known as 'bootstrap' photography. Targets for bootstrap photography were listed by GLEP and included Censorinus and Lalande (Table 50).

Table 45. GLEP Set B candidate sites presented to ASSB.					
Name	features	coordinates	Name	features	coordinates
Censorinus	fresh highland impact crater	0° 17' S, 32° 39' E	Mösting C	fresh impact crater in mare	1° 55' S, 8° 03' W
Rima Littrow	mare ridge, dark mantle material	21° 35' N, 28° 56' E	Hipparchus	old crater basin fill	4° 36' S, 3° 40' E
Abulfeda	volcanic crater chain, deposits, in highlands	14° 50' S, 14° 00' E	Prinz	double sinuous rille, access to its mouth area	25° 57' N, 43° 40' W
Rima Hyginus	linear rille, volcanic deposits	7° 52' N, 6° 07' E	Gassendi	crater, rilles, mare deposits	17° 50' S, 40° 20' W
Rima Hadley	young sinuous rille, mountains of Imbrium basin rim	25° 02' N, 2° 55' E	Dionysius	fresh crater, light and dark rays	2° 31' N, 17° 49' E
Tycho	young large highland impact	41° 08' S, 11° 35' W	Alexander	domes and rilles near large basin	37° 46' N, 14° 06' E
Copernicus Peak	large crater central peaks	9° 36' N, 19° 53' W	Alphonsus	dark halo craters, rilles and faults in crater	13° 35' S, 4° 11' W
Copernicus Wall	large crater walls, impact melt	10° 22' N, 19° 59' W	Rima Bode II	linear rille, dark mantle, volcanic deposits	12° 47' N, 3° 49' W
Schröter's Valley	large and small rilles, dome and rille complex on plateau	24° 36' N, 49° 03' W	Copernicus CD	dark mantle, domes, on Copernicus ejecta	6° 32' N, 14° 58' W
Marius F	(volcanic domes, rilles and flows	15° 10' N, 56° 31' W	Tobias Mayer P	dome, rille, highland ridge	13° 18' N, 31° 11' W
Fra Mauro	Imbrium ejecta	3° 45' S, 17° 36' W	Aristarchus	young large impact crater	24° 24' N, 47° 50' W

Table 46. GLEP and ASSB Apollo landing sequences, 10 July 1969

mission	GLEP proposal	GLEP alternative site	GLEP site geological characteristics	ASSB site
G-1	Site 2		Old mare surface	Site 2
H-1	Site 5 or 4		Young mare surface, Kepler ejecta	Flamsteed or Site 7
H-2	Fra Mauro Formation	Hipparchus, Cayley Formation	Imbrium ejecta (alternate sites: highland plains areas)	Fra Mauro Formation
H-3	Rima Bode II	Hyginus, Littrow	Valley, dark volcanic deposits	Censorinus
H-4	Censorinus		3.8 km diameter fresh impact crater	Rima Bode II
J-1	Copernicus peaks		Central peaks, volcanic (?) mounds on floor	Tycho rim
J-2	Marius Hills		Variety of volcanic domes and flows	Copernicus peaks
J-3	Tycho		Surveyor 7, flows, ejecta	Marius Hills
J-4	Rima Prinz I	Schröter's Valley	Sinuuous rille (alternative site is older)	Descartes
J-5	Descartes	Abulfeda	Highland volcanic materials	Rima Prinz I

One type of feature omitted from the Set B sites was a so-called ‘caldera’ crater. These craters differed in appearance from typical impact craters, having smooth walls and floors at about the level of the exterior surface. Some researchers considered them to be volcanic calderas rather than impact craters. GLEP was considering several as possible landing targets. The highest priority was Gaudibert (11° S, 38° E), the second Lassell (15° S, 8° W), and the lowest priority was assigned equally to Gambart (1° N, 15° W) or Sabine and Ritter (2° N, 20° E), shown in Figure 137. The priority reflected the desire later in the landing sequence for higher latitude sites, giving better geophysical data and orbital photographic coverage.

These considerations shaped the list of sites for which additional orbital photography was needed for site planning. Set B sites needing more images were: Mösting C, Abulfeda, Rima Hadley, Copernicus CD and Censorinus. Other possible sites not included in Set B but needing more images were: Gambart, Gambart C, Mösting, Hevelius, Gaudibert, Sabine/Ritter, Posidonius, Dawes, Vitello, Descartes, Boscovich, Davy and Lassell.

ASSB minutes for this meeting also noted the following points. The need to sample materials of different ages to establish lunar geological history was emphasized. The idea that Apollo landings might be made in the lunar ‘afternoon’ (near the eastern terminator, a few days before sunset) was finally abandoned. All landings would be made in the early lunar morning. Lastly, an extended version of the Lunar Module (ELM) with a large vertical solar panel mounted on one side, providing extra electrical power for a longer stay, was finally dropped from consideration.

Figure 137C shows the ten sites scheduled for Apollo landings by GLEP and ASSB (Table 46) and other sites mentioned in the text, indicating which sites required future photography. The board also considered sampling objectives at six future sites at this meeting (Figure 138). The Censorinus sites were shown but not explained in ASSB minutes.

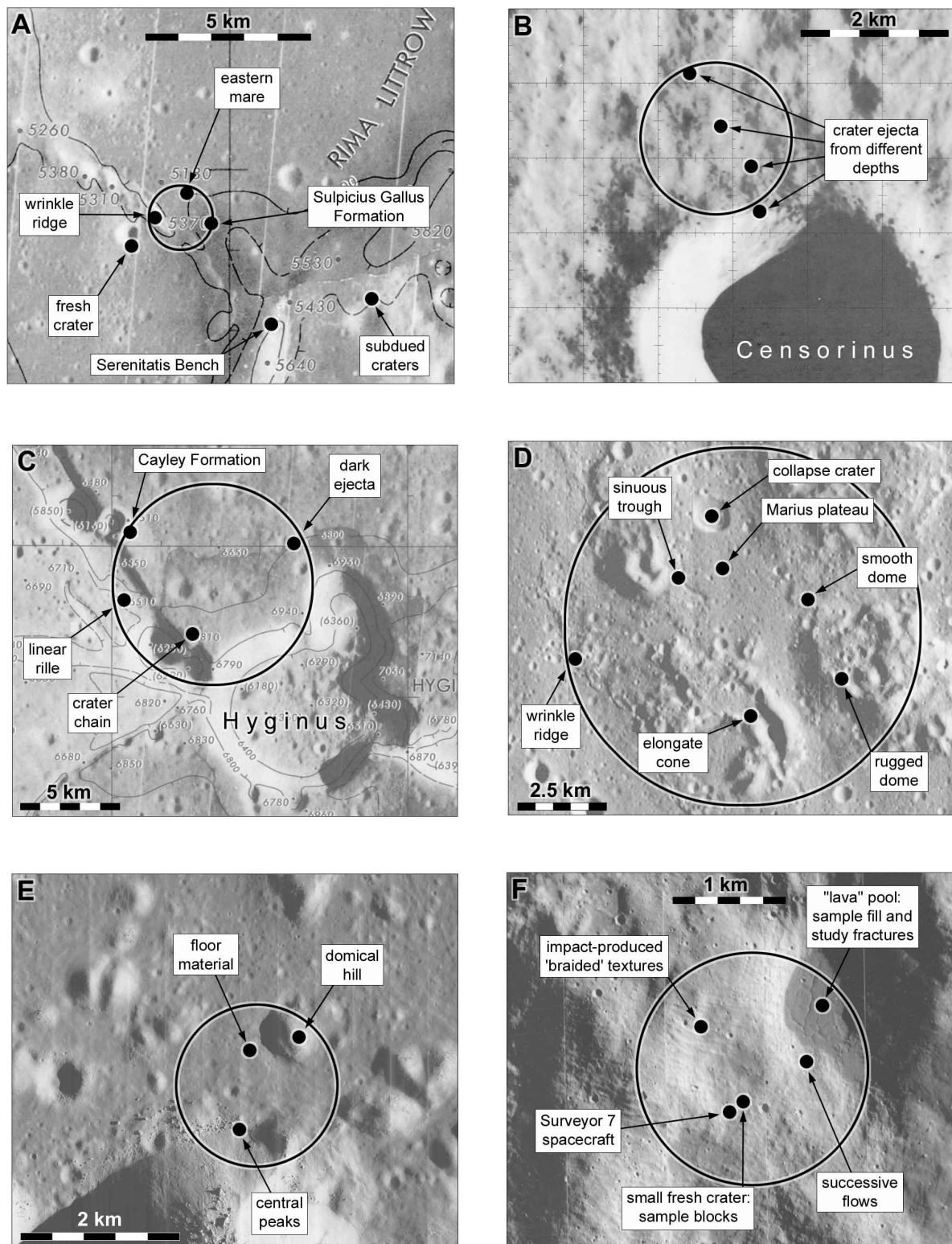


Figure 138. Sampling objectives at six later Apollo sites. A: Littrow. B: Censorinus. C: Hyginus. D: Marius. E: Copernicus. F: Tycho. Large circles: range of expected mobility from the landing site at the center of the circle. Black dots: sampling locations.

Table 47. Pinpoint landing sites, Newell Trask memo, 19 June 1969

Apollo Landing Site 2				
Site	Image	Framelet	Distance from data edge (cm)	Distance from top (cm)
1	LO2-084	450	24.3	1.6
2		439	27.5	1.7
3	LO2-085	572	6.3	1.5
4		575	12.0	0.4
5		573	12.8	0.6
6		565	9.1	0.5
7		565	13.4	1.6
8		568	19.4	0.4
Apollo Landing Site 3				
Site	Image	Framelet	Distance from data edge (cm)	Distance from top (cm)
1	LO2-121	284	11.0	1.8
2		288	20.0	1.8
3		279	32.8	1.5
4	LO2-122	416	10.8	1.2
5		409	12.2	1.0
6		403	10.5	1.5
7		408	17.6	1.8
8		410	27.8	0.5
Apollo Landing Site 5				
Site	Image	Framelet	Distance from data edge (cm)	Distance from top (cm)
1	LO3-166	592	18.1	1.8
2		594	20.8	1.0
3		584	8.8	1.7
4		588	28.1	0.4
5		589	18.5	0.3
6	LO3-167	717	10.8	0.5
7		716	7.8	1.7
8		726	4.2	0.8
9		721	14.5	1.2

GLEP argued against landing at a Surveyor site, feeling that the Surveyor activities would detract from geological fieldwork, and that the public would misunderstand the secondary nature of the Surveyor activities and label the landing a failure if the old lander was out of walking range from the LM. ASSB placed more importance on the Surveyor targets than did GLEP, and the Surveyor 3 option offered better opportunities for orbital photography than the other western sites, which was a strong point in its favour. This site was now gaining favour compared with Surveyor 1. When the time came to select a site for Apollo 12, Surveyor 3 (Site 7) was the final choice. The reasons included better bootstrap photography for Fra Mauro and Davy and better recycling (launch delay) alternatives. Most importantly, however, USGS now noted that a ray from Copernicus crossed the Surveyor 3 site (Figure 74C), suggesting that Copernicus ejecta could be collected there, as a landing in Copernicus now seemed unlikely (Wilhelms 1993).

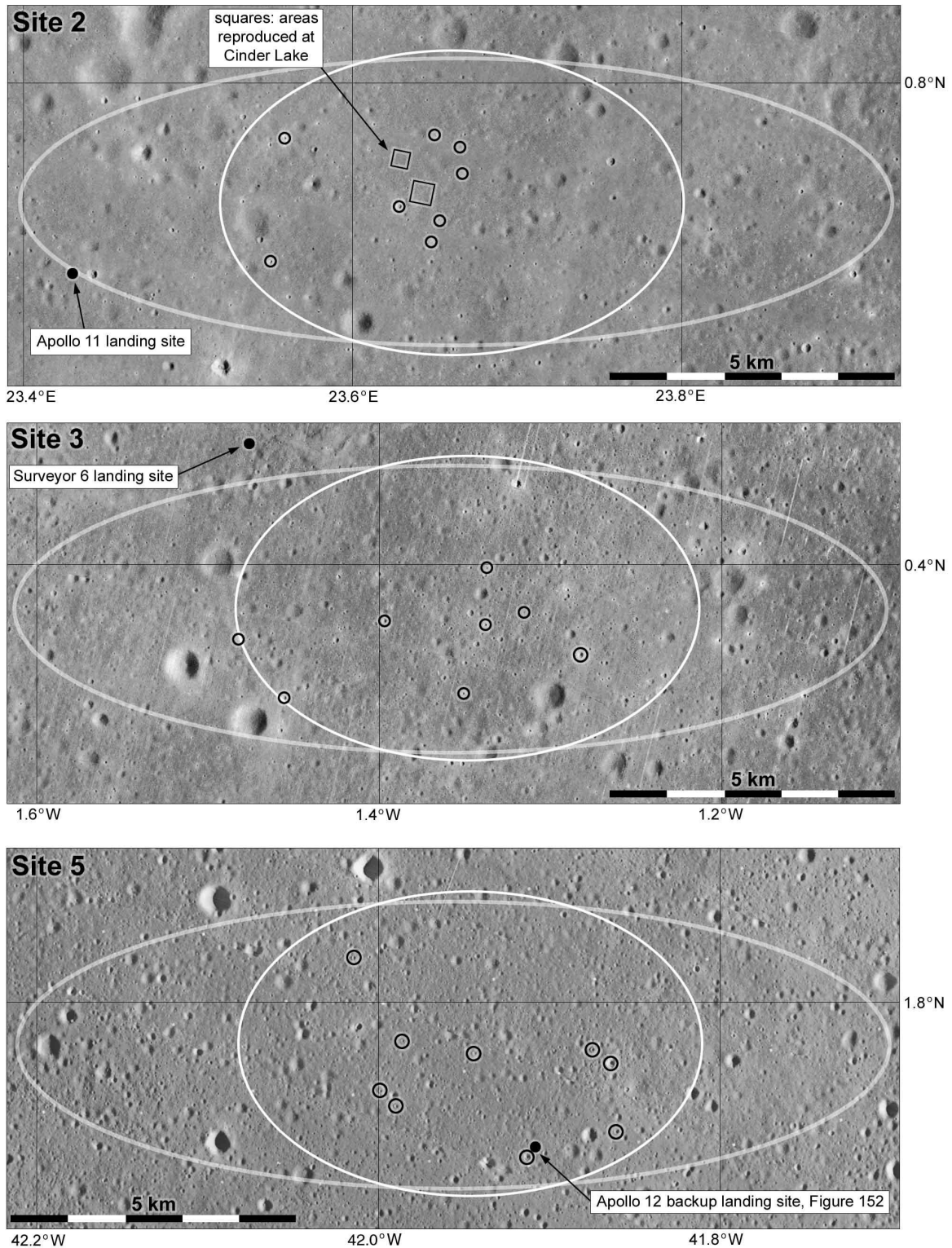


Figure 139. Pinpoint landing targets identified by USGS geologist Newell Trask, from Table 47. Circles indicate the small fresh craters chosen by Trask as science targets, with landing sites nearby. In site 2 the two Cinder Lake model areas (Figure 140A) are also indicated.

One GLEP argument against the Surveyors was that they were not the only suitable redesignation points for a pinpoint landing. Small fresh concentric-ring or blocky-rimmed craters were common in the landing ellipses and would form useful targets. Geologist Newell Trask (USGS Menlo Park) was asked to identify suitable examples and provided a list in a 19 June 1969 memo to James Sasser of MSC. He listed 8 points in Site 2, 8 in Site 3 and 9 in Site 5 (Table 47, Figure 139). The landing points were identified by measurements in centimetres on individual framelets of Lunar Orbiter images, which were usually printed at a standard size, and all are adjacent to small fresh craters. In Figure 139 the assumed crater targets are shown rather than the precise point nearby indicated by Trask, though in some cases the identity of the intended crater is ambiguous.

Figure 139 also shows two rectangular areas in Site 2 which were carefully recreated at 1:1 scale in the dry lake bed of Cinder Lakes, 18 km northeast of Flagstaff. Figure 140A shows these in more detail. Crater Field 1 was constructed in two phases, the first in July 1967, the second 3 months later, by setting off explosives in amounts and locations intended to reproduce the pattern of craters seen in the Lunar Orbiter image (Kring, 2008). Crater Field 2 was created in a region where the dark volcanic cinders were deposited on top of a lighter clay bed, so brighter ejecta would be more visible. Three sets of explosions were set off so the crater ejecta would overlap in a sequence resembling what might be expected on the Moon. A ramp was constructed in Crater Field 1 and a simulated Lunar Module was built on it with its windows at a height which duplicated the view astronauts would have from a landed LM, to provide experience in locating the landing site. Another crater field was created at Black Canyon, south of Flagstaff. Later crews trained here, as at many places around North America and beyond, practicing field work techniques and rover driving, but the Apollo 11 astronauts did not have time to train at Cinder Lake. These sites were used again in 2024 for Artemis and robotic mission simulations, replicating the low Sun angle at polar sites by working at night with large floodlights.

Kring, D. A., 2008. Cinder Lakes Crater Field, Arizona. Lunar Analogue Test Site. Briefing notes.

https://www.lpi.usra.edu/science/kring/lunar_exploration/CinderLakesCraterField.pdf

Wilhelms D. E., 1993. *To a Rocky Moon: a geologist's history of lunar exploration*. Tucson: University of Arizona Press.



13 July 1969: Luna 15

Luna 15 was the third of the Soviet Union's new robotic sample return missions, after Lunas 1969B and 1969C, and the first to leave Earth successfully. This mission was the last possible chance to return lunar material to Earth before the United States. It was launched from Baikonur at 02:55 UT on 13 July 1969, three days before Apollo 11. This caused some concern about deliberate or accidental interference with Apollo, but assurances were soon received from the Academy of Sciences of the USSR via Apollo 8 astronaut Frank Borman, who had visited Russia, that there would be no problems of this type (Huntress and Marov, 2011).

The 2718 kg spacecraft made a trajectory correction on 14 July, and entered a 133 by 295 km, 150 minute period lunar orbit (Huntress and Marov say 240 to 870 km) inclined 126° to the equator at 10:00 UT on 17 July. The intended orbit was 100 by 100 km so Luna 15 adjusted its orbit several times, first to 94 by 220 km on 18 July, then to 85 by 221 km on 19 July on its 25th orbit, finally changing to 16 by 109 km, inclined 127°, with a period of 114 minutes on the 39th orbit on 20 July. This potentially allowed for a landing 2 hours before Apollo 11. Radar altimetry from the first low pass showed a rougher surface than anticipated so the landing was delayed, losing the chance to return a sample before Apollo 11 which would have been a great propaganda victory for the Soviet Union.

The lander was directed to land on its 52nd orbit at 15:46 UT on 21 July, after 86 communications sessions and following Apollo 11's EVA. Luna 15 crashed at about 17° N, 60° E (Huntress and Marov, 2011), at 15:51 UT, hitting the surface at a velocity of 480 m/s as Apollo 11's Lunar Module Eagle was preparing to launch from the lunar surface. The velocity shows that substantial braking had occurred before impact. Causes may have included attitude control problems, navigational errors induced by mascons and/or inadequate knowledge of local elevations.

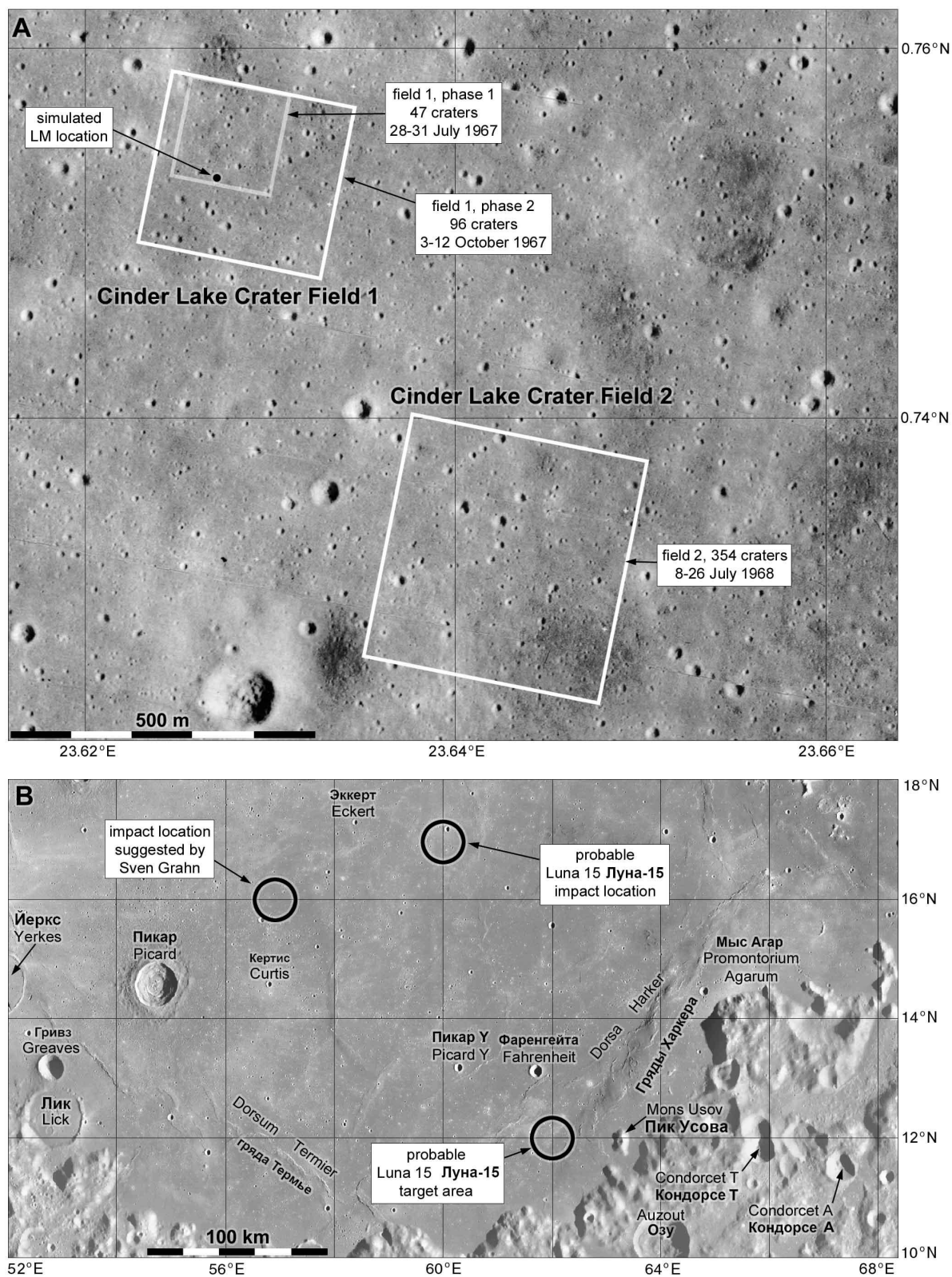


Figure 140. Areas in Apollo Site 2 reproduced at Cinder Lake, Arizona, and Luna 15 impact site. A: the parts of Site 2 reproduced at 1:1 scale at Cinder Lake near Flagstaff, Arizona, mapped on Lunar Orbiter 2 image 2-085-H2. B: the Luna 15 impact area.

The location of the impact is given differently in various sources. The most consistent interpretation seems to be that the target area was near the point later visited by Luna 24 (near 12° N, 62° E), and that the impact occurred near 17° N, 60° E, probably uncertain by up to 20 km. An impact location of 16° N, 57° E was reported by Sven Grahn, but the original source of this is unclear. The Philip's map of the Moon, 2003 edition, listed the Luna 15 location at 17° N, 49° E and depicted it at 17° N, 53° E, both probably incorrect. Johnson (1979) suggested that Luna 15 was a Lunokhod rover rather than an attempted sample return mission, but this is now known to be incorrect.

Some reports suggested the spacecraft was capable of photographing the lunar surface, but this means after landing, not from orbit. Some science was performed, however, since the use of the radar altimeter made it possible to estimate the average density of the lunar surface layer (Marov, 2023).

Huntress, W. T. and Marov, M. Ya., 2011. *Soviet robots in the solar system. Mission technologies and discoveries*. New York: Springer Praxis.

Johnson, N. L., 1979. *Handbook of Soviet lunar and planetary exploration*. Science and Technology Series, v. 47. San Diego: Univelt, Inc.

Marov, M.Y., 2023. Exploration of the Moon by automatic spacecraft. *Cosmic Research*, v. 61, no. 1, pp. 46-69.



16 July 1969: Apollo 11

Apollo 11 fulfilled President John Kennedy's directive with a safe lunar landing and return to Earth. The crew consisted of Neil A. Armstrong, Commander (who had previously flown on Gemini 8), USAF Lt. Colonel Michael Collins, Command Module Pilot (also flew on Gemini 10) and USAF Colonel Edwin E. Aldrin, Jr., Lunar Module Pilot (also flew on Gemini 12). The backup crew for this mission was Jim Lovell (Gemini 7, Gemini 12, Apollo 8, later Apollo 13), Fred Haise (later Apollo 13), and William Anders (Apollo 8). The spacecraft call signs were "Columbia" (CSM) and "Eagle" (LM). The Apollo 11 Command Module is displayed in the National Air and Space Museum in Washington, D. C.

The instruments deployed on the surface were the Solar Wind Composition (SWC) experiment, a Swiss device consisting of a thin metal sheet which would capture particles from the solar wind, a stream of protons and other ions emanating from the Sun, a solar-powered Passive Seismic Experiment (PSE) designed to monitor impacts and internal 'moonquakes', and a Laser Ranging Retroreflector (LRRR) designed to return laser photons to Earth for ranging and dynamical studies. The PSE operated for two lunar days and the passive LRRR was still functional in 2025 but has gradually degraded. The PSE included a solar cell degradation experiment called DTREM (Dust, Thermal and Radiation Engineering Measurements) to monitor loss of voltage output due to radiation damage and dust accumulation. The PSE and LRRR together constituted EASEP, the Early Apollo Surface Experiment Package.

Apollo 11 carried three 70-mm cameras, one additional data camera, two 16-mm data acquisition cameras, and one 35-mm stereoscopic closeup camera (ALSCC, Apollo Lunar surface Close-up Camera). The photographs returned included 1359 70-mm frames, 58,134 frames of 16-mm automatic photography, and 17 stereoscopic pairs from the close-up camera. The ALSCC was often referred to as the Gold Camera because it was strongly promoted by Thomas Gold, a Cornell University professor who had raised unfounded concerns about the ability of the lunar surface to support the weight of the LM.

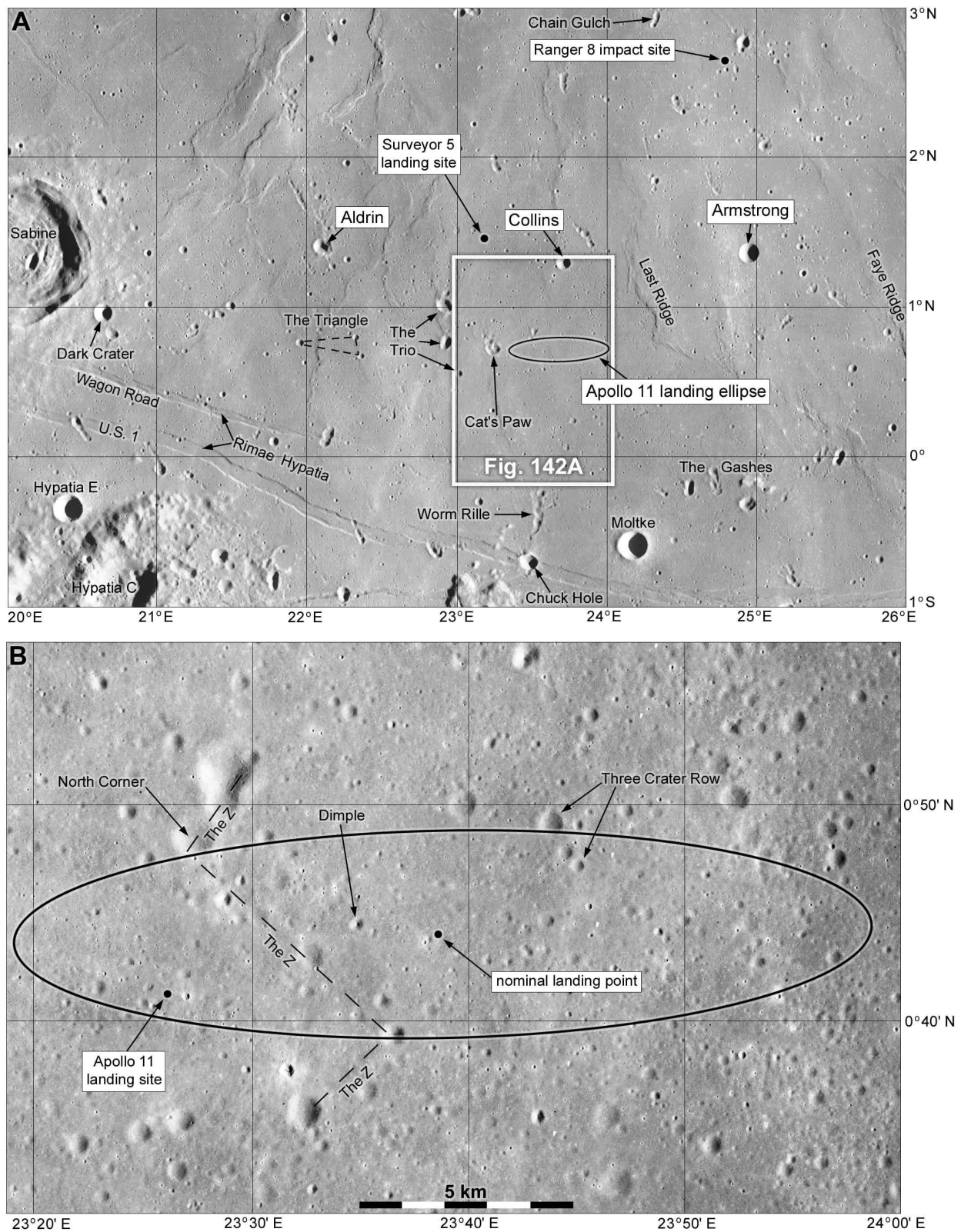


Figure 141. Apollo 11 landing area. A: landing region with unofficial names and craters named officially after the crew. B: final 20 km by 5 km landing ellipse with unofficial names.

The launch on a Saturn V rocket from pad 39A of the Kennedy Space Center at Cape Canaveral, Florida took place at 13:32 UT on 16 July 1969. Apollo 11 was first placed in a parking orbit, and after 1.5 orbits the S-IVB stage reignited at 16:16 UT for the 5.8 minute translunar injection burn which set the spacecraft on its lunar trajectory. After 33 minutes the CSM separated from the S-IVB upper stage, then turned around and docked with the LM at 16:56 UT. The S-IVB stage was then sent into a solar orbit by one last burn. On 17 July during the translunar coast a small trajectory correction was made.

The main engine burned for 357.5 seconds starting at 17:22 UT on 19 July while the spacecraft was over the lunar farside to insert the spacecraft into a 111 by 306 km lunar orbit. A later burn made the orbit nearly circular (100 by 113 km). On 20 July astronauts Armstrong and Aldrin entered the LM to prepare for the landing. At 18:12 UT the LM separated from the CSM, and its descent engine fired for 30 seconds at 19:08 UT to drop the orbital low point to 14.5 km above the lunar surface. Finally at 20:05 UT the descent engine fired and the powered descent to the lunar surface began.

The spacecraft landed roughly 1500 m south and about 7 km west of its intended position. The flight computer was bringing the LM down in a rocky area near the north rim of the then-unnamed West Crater ('targeted landing point' in Figure 142C), but Armstrong flew manually on to a smooth spot 500 m further west. It took some time to establish where the landing site was, and it appears from the voice transcripts that the name West Crater may have originated during that search. It was small enough that it did not warrant a name on pre-landing maps. It supposedly takes its name from its location near the west end of the landing ellipse (outside the original IIP-6 ellipse) but also can be seen as commemorating Mareta N. West (1915-1998), one of the USGS astrogeologists at Flagstaff who worked on Apollo site selection, including this site. A small sample of her ashes was later launched into space on the first Astrobotic mission to the Moon on 8 January 2024. That mission failed soon afterwards and burned up in Earth's atmosphere on 18 January. The name Mareta was given in 2025 to a small crater at the Lunar-VISE landing site on the Gruithuisen Domes.

The small crater west of West Crater is Little West Crater, shown in Figure 142D and in the partial panorama in Figure 145H. The Apollo Lunar Surface Journal (ALSJ) website (<http://www.hq.nasa.gov/alsj/>) referred to this crater until about 2010 as 'East Crater' from its location relative to the landed LM, and a small crater on its rim was named Rim Crater.

The LM landed at 20:18 UT on 20 July at 0.67° N, 23.47° E in contemporary coordinates, refined to 0.67415° N, 23.47314° E in LRO coordinates, at landing site ALS-2 in Mare Tranquillitatis. Armstrong announced the landing with the words "Houston, Tranquility Base here – the Eagle has landed." The name Tranquility Base has been used ever since for this spot, usually in its official Latin form 'Statio Tranquillitatis' (Stoyanka Spokoistviya on Russian maps). After landing the crew prepared for an immediate departure if it should be required, gave an initial commentary on the landscape, and ate a meal. Aldrin privately took communion just before the meal, using wine and bread with a chalice brought from his church in Webster, Texas.

The crew prepared for their Extravehicular Activity (EVA), or 'moonwalk', and opened the hatch of the cramped cabin. Armstrong exited first, backing out of the hatch and discarding a bag of wrapping materials and other items no longer needed. This 'jettison bag' fell near the footpad (Figure 143B). He then pulled a cord to deploy a television camera mounted on the side of the spacecraft, so the initial surface activities could be seen on Earth. Armstrong climbed down the ladder mounted on the landing leg, in shadow but illuminated sufficiently by light reflected from the surrounding ground. A final jump brought him to the footpad, from which his first act was to jump up onto the base rung of the ladder to show he could reach it. This activity was watched on Earth by a worldwide television audience (including the author).

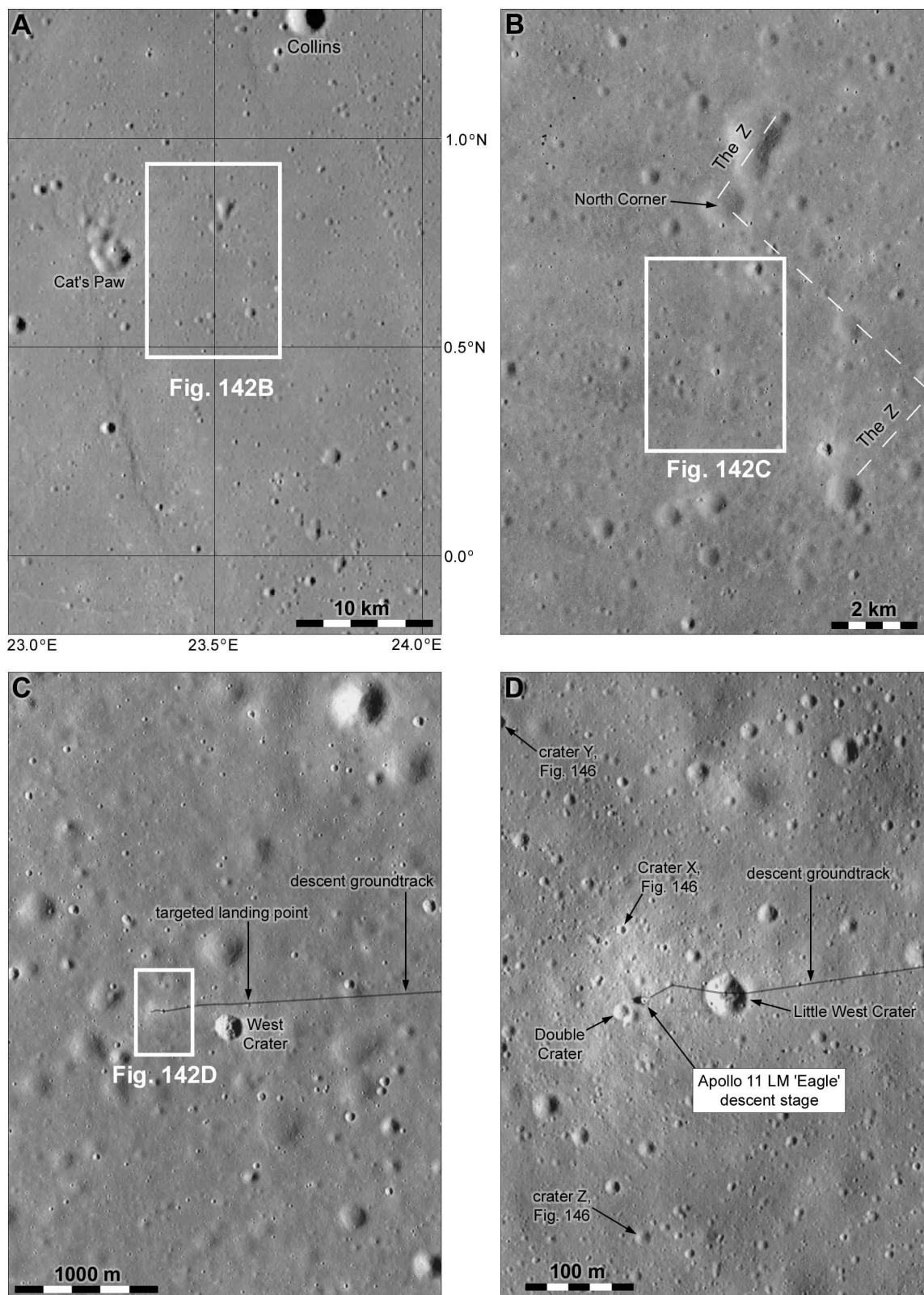


Figure 142: The Apollo 11 landing site. A: LROC wide angle mosaic. B: Lunar Orbiter image LO2-085-M. C, D: details of LROC image M175124932R. C and D include the LM descent groundtrack.

Armstrong stepped onto the lunar surface at 02:56 UT on 21 July, with the words “That’s one small step f’ra man, one giant leap for mankind” (the slurred pronunciation of ‘for a’ is usually misreported as ‘for’, as if enunciation is more important than intention in common speech). The camera used by the crew to take photographs on the surface was passed down from the cabin on a lanyard and used to take a panoramic view of the surface. Then the first lunar material, some regolith and small rocks called the contingency sample, was collected quickly with a sampling tool in a sunlit area just north of the footpad and placed in a pocket. This ensured that some lunar surface material would be returned if a hasty departure became necessary. The sampler handle was pushed into the soil to test its hardness, and a ring from the sample bag was thrown under the LM near the footpad and jettison bag. These items were left on the surface

Aldrin left the cabin and descended 19 minutes after Armstrong. He also tried to jump back up onto the lower rung, succeeding on the second attempt. The astronauts familiarized themselves with moving and working on the surface and examined the LM and the surface, noting that the engine exhaust did not form a visible pit under the LM despite clouds of dust almost hiding the surface during the landing. Armstrong then removed the wide angle lens from the TV camera and replaced it with a new lens. A large foldable antenna was stowed on the LM, but it was not needed for the TV transmission and was not deployed. The astronauts then uncovered a plaque on the LM leg and read its message, ‘Here men from the planet Earth first set foot upon the Moon, July 1969 A.D. We came in peace for all mankind’. The plaque also carried a map of Earth in two hemispheres and the signatures and names of the three astronauts and President Richard Nixon.

Armstrong moved the TV camera from its mount on the LM on the north side of the west-facing ladder, and erected it on a tripod stand 18 m northwest of the LM while Aldrin payed out its cable. Armstrong pointed the camera in several directions to give scientists in Houston a view of the area, while Aldrin prepared equipment for later sampling and set up the SWC. It was exposed to the solar wind for 77 minutes, then rolled up and returned to Earth for analysis. Next a United States flag was set up, and the astronauts spoke live over the radio link with President Nixon, who was in the oval office at the White House. The flag did not constitute a territorial claim, which would not have been permitted by the Outer Space Treaty of 1967, and served only to identify the site as having been visited by Americans.

Aldrin followed the flag ceremony with tests of mobility and regolith behaviour, kicking the dust to watch its motion. Armstrong had some trouble keeping his feet clear of the TV cable and had to be guided away from it by Aldrin. Aldrin then performed a series of footprint observations, and Armstrong set about collecting the bulk sample (Figure 144) from several areas a little further out than the contingency sample and likely to be less contaminated than the contingency sample. Aldrin used the Hasselblad camera during this period, though normally it was carried by Armstrong. They only used one camera during the EVA, though a spare was left in the LM and could be retrieved if necessary. Armstrong sealed the bulk sample in a box at a fold-out table on the side of the LM, and as he was doing so Aldrin photographed him, taking the only clear image of Armstrong on the surface. He also took several image sequences to create 360° panoramic views of the surface.

Armstrong now removed the ALSCC from the equipment storage bay and used it to take several images near the LM (Figure 143B). Aldrin moved to the opposite side of the LM to remove the scientific package (EASEP) from its storage area as Armstrong put the ALSCC down and took another panoramic image sequence. Aldrin carried the two EASEP instruments to a flat area south of the LM, where Armstrong had just used the ALSCC to image the top of a rock. He put the LRRR down first and carried the PSE a little further south for deployment. As he extended the solar panels and levelled the seismometer, Armstrong deployed the LRRR and oriented it correctly. A fitting which held the LRRR secure in its storage bay on the LM was discarded next to the instrument (Figure 143B). Alternate deployment positions for LRRR and PSE were north, east and west of the LM at about the same distance, if obstacles made the southern location unsatisfactory.

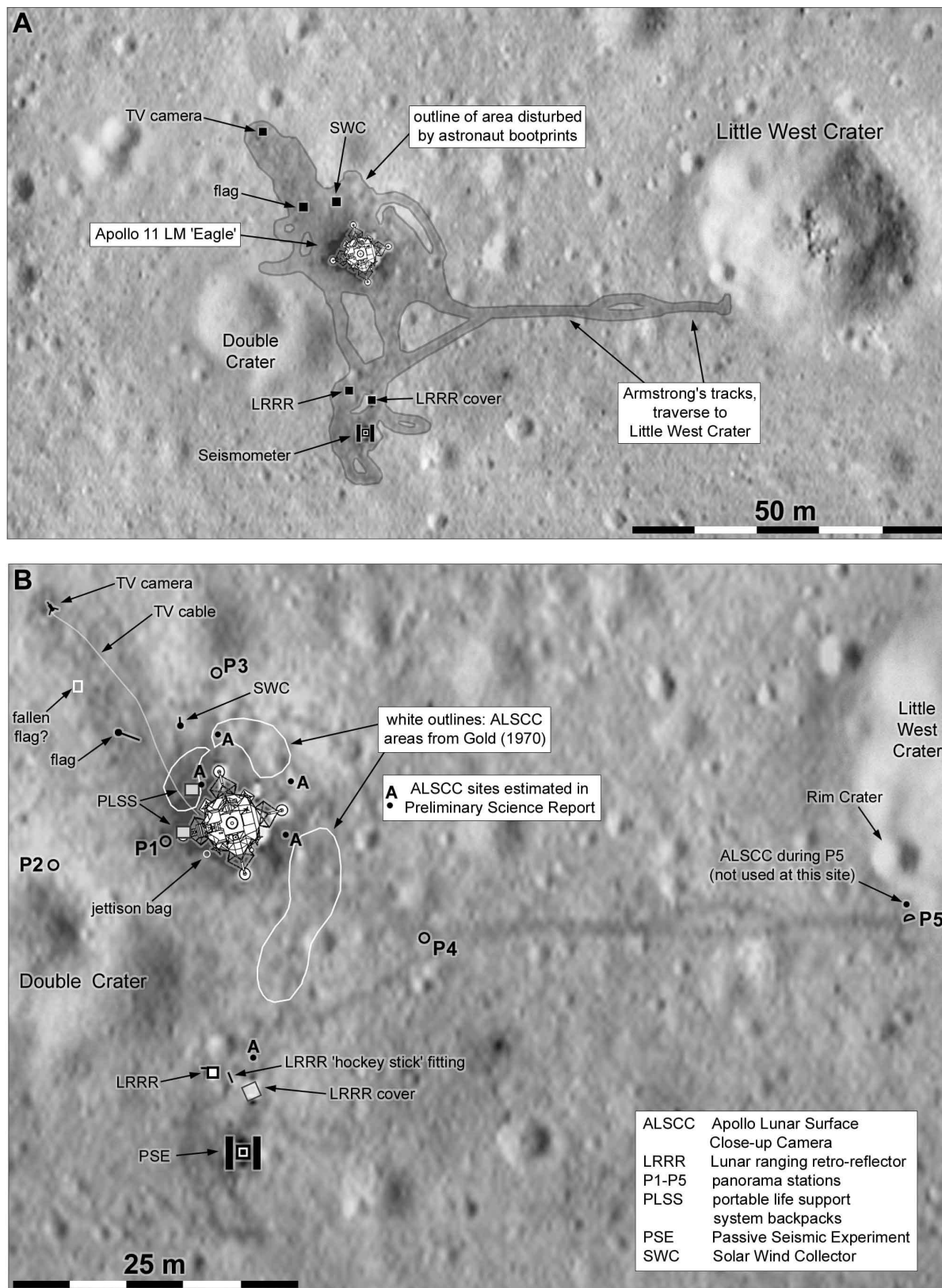


Figure 143. Apollo 11 landing site. A: area traversed by astronauts. B: Equipment and photography locations.

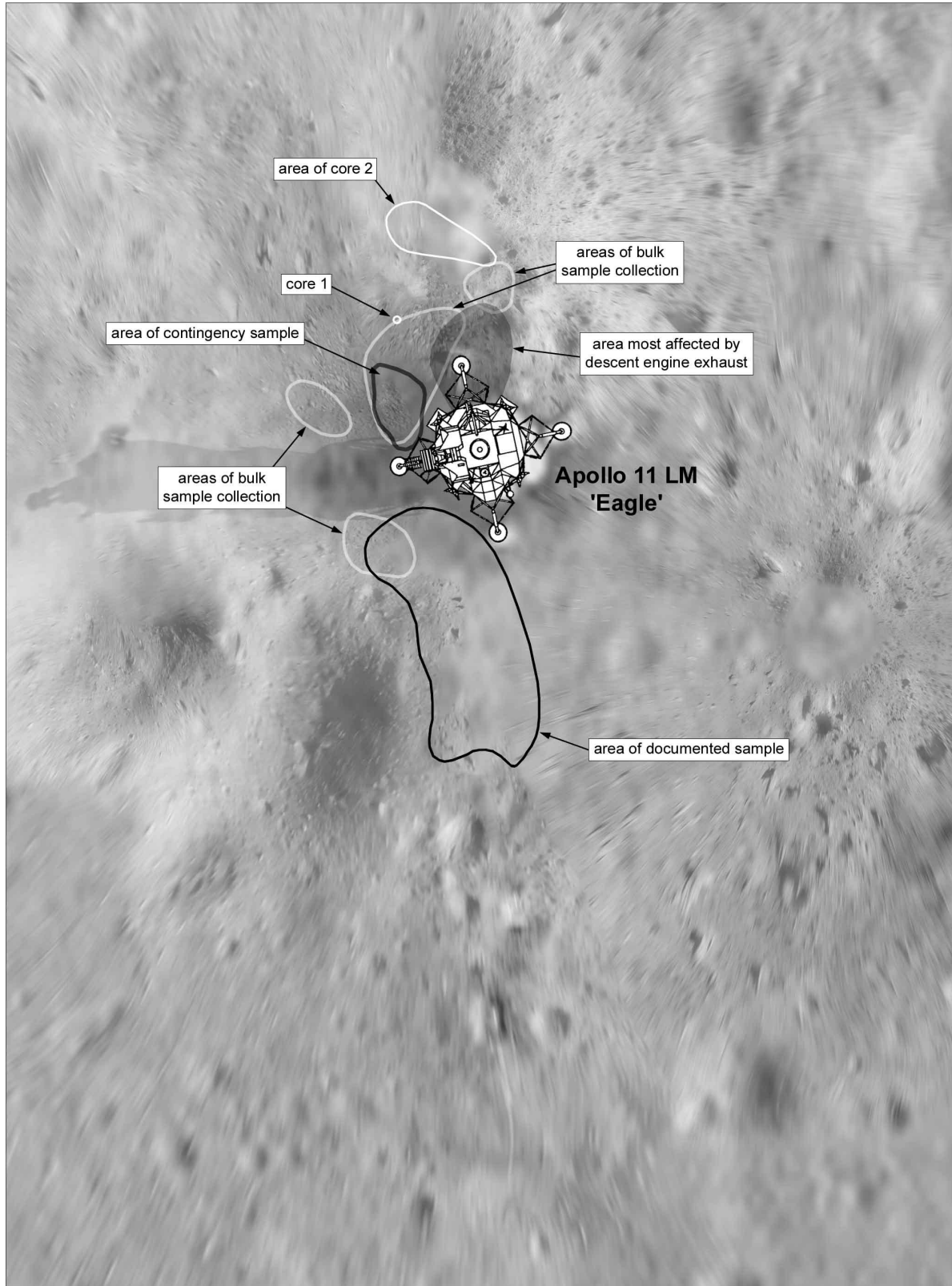


Figure 144. Apollo 11 site and sampling areas. The map consists of surface panoramas projected onto an LROC base image.

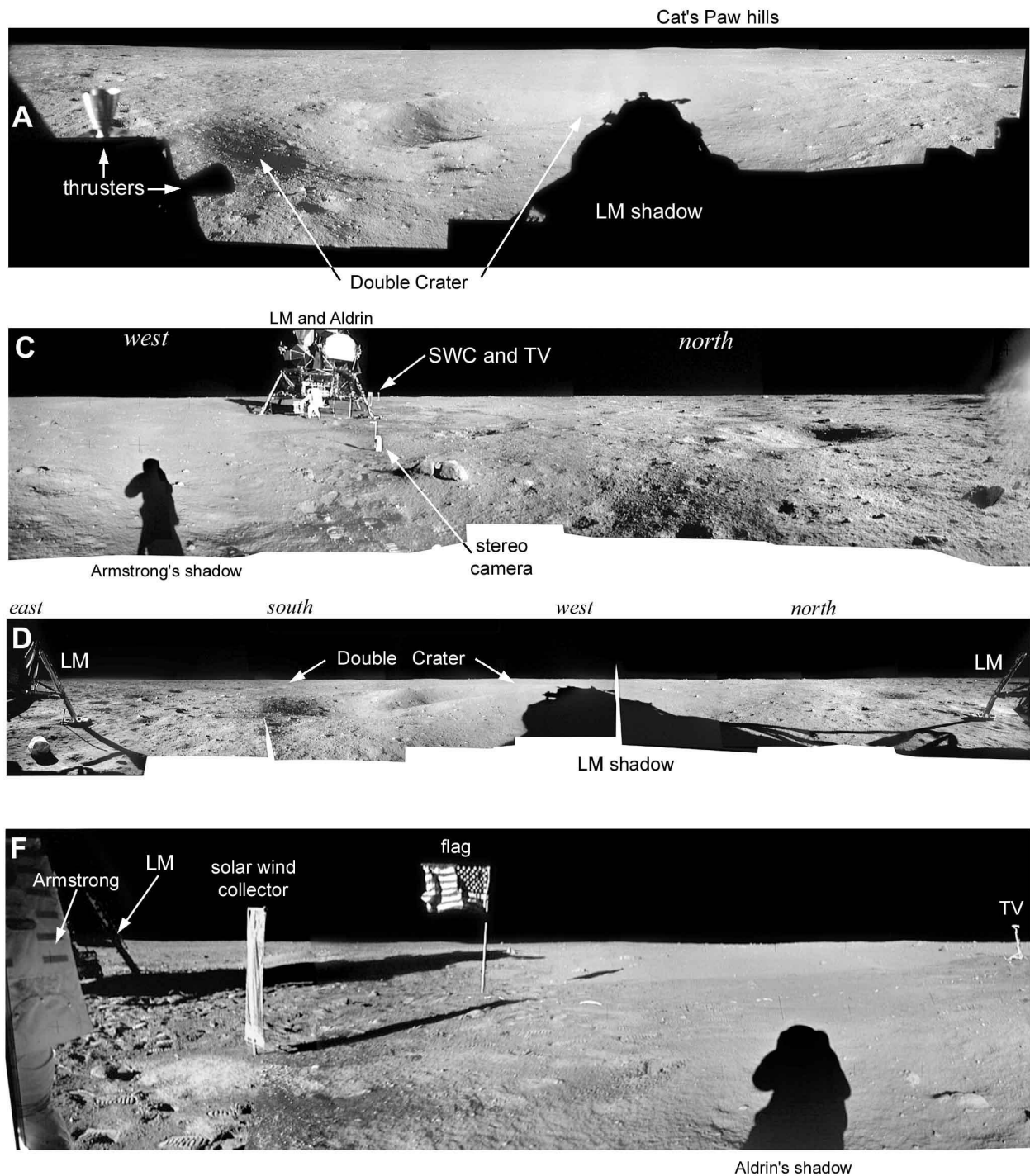
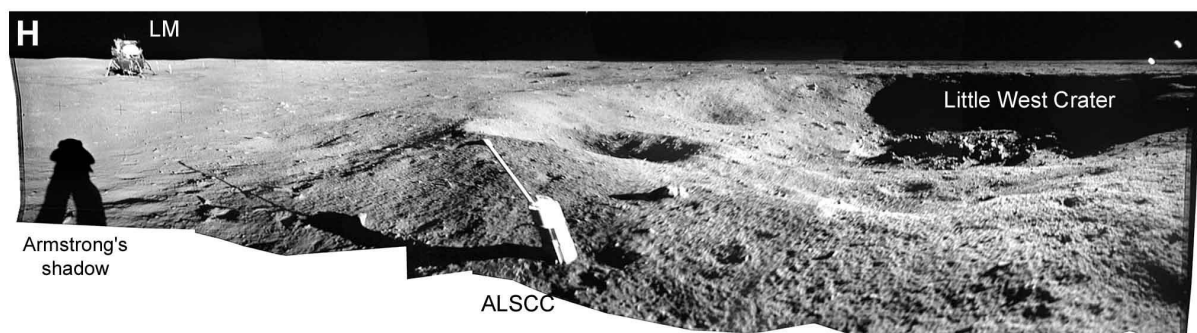
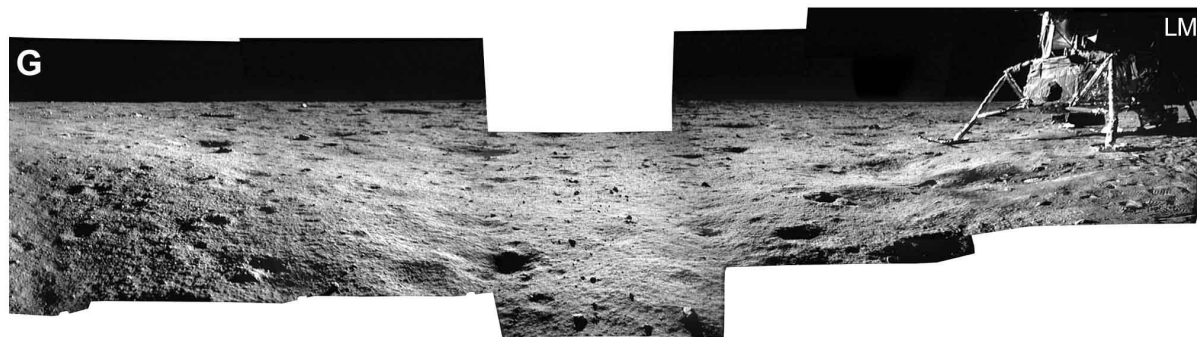
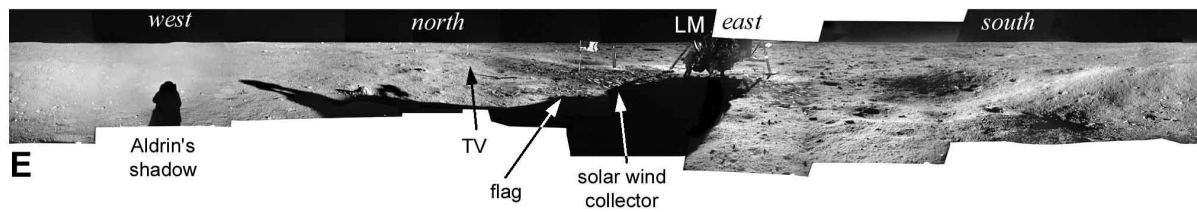
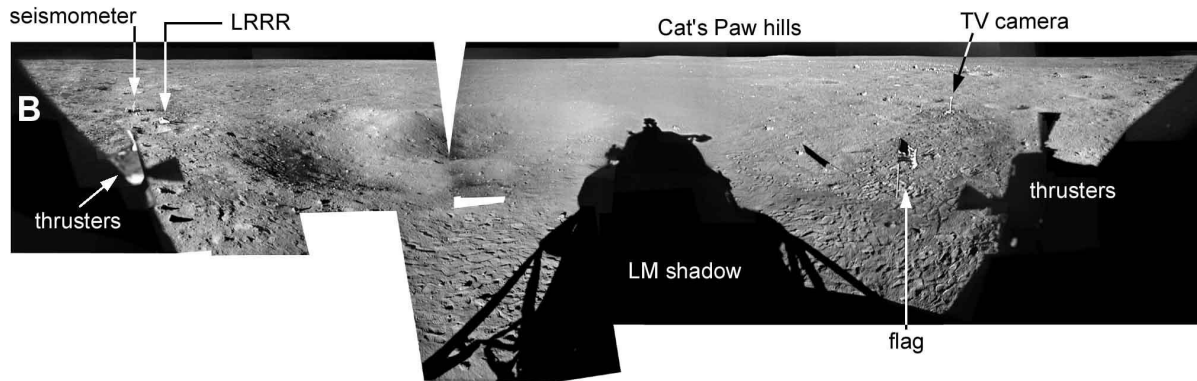


Figure 145 (both pages). Apollo 11 panoramas. A: view to the west from the LM windows just after landing, showing Double Crater and hills forming the rim of Cat's Paw, 5 km from the landing site. B: view from the LM windows after the EVA, showing footprints and items left on the surface. C (across both pages): panorama taken from southeast of the LM during the EVA. Aldrin is working in front of the LM. D: panorama taken just west of the LM (Armstrong was standing in the LM shadow) at the start of the EVA. E: panorama taken from west of the LM. F and G: sections of a panorama taken north of the LM. H: partial panorama taken near the end of the EVA at Little West Crater.



The EVA was now drawing to a close. Aldrin returned to the LM and collected the core tube which would be pushed into the regolith to retrieve a core sample showing stratigraphy, or variations with depth. Armstrong quickly ran over to Little West Crater, took half a panorama, and returned. He carried the ALSCC there and back but did not use it at the crater. As he came back Aldrin hammered the core tube into the ground near the SWC, noting the regolith was very compacted under the loose surface and hard to penetrate with the tube. The core was only about 10 cm deep. As Aldrin was extracting the core and capping the tube to hold the sample in, Armstrong became tangled in the TV cable again and Aldrin again helped him get free. Then Aldrin collected another core a little to the north while Armstrong very quickly collected a documented sample south of the LM. The documented sampling involved taking images of the sampled rocks or regolith before and after sampling, but time did not permit this to be done very effectively.

Aldrin retrieved the SWC collector sheet, rolled it up and placed it in a bag which was put in the box with the other samples. He pushed the SWC support pole back into the ground and left it there. The astronauts retrieved film magazines and prepared to leave the surface. Aldrin climbed up the ladder first, while Armstrong hastily filled the sample box with additional regolith. Then Armstrong pulled the sample boxes and film magazines up to the cabin with a lanyard, where Aldrin could stow them in the LM. The seismometer was already transmitting signals and could detect astronaut movements, but the LRRR was not used during the mission despite an effort at Lick Observatory because its position was still uncertain.

Aldrin was carrying a small memorial package which contained an Apollo 1 patch, medals commemorating the deceased Soviet cosmonauts Yuri Gagarin and Vladimir Komarov, a gold olive branch and a silicon disk containing messages from many Heads of State of nations around the world. He now dropped it from the open cabin onto the surface, where Armstrong positioned it with his foot. Other special cargo included fragments of the Wright Flyer, the aircraft flown at Kitty Hawk, North Carolina on 17 December 1903, which were returned to Earth and are now in the National Air and Space Museum in Washington, D. C. Armstrong now mounted the ladder and entered the cabin at 05:11 UT, ending an EVA which had lasted 151 minutes. The astronauts had traversed a total distance of about 250 meters and collected 21.7 kg of lunar rock and soil, which was later dated about 3.6 to 3.8 billion years old. Apart from the local basalts of Mare Tranquillitatis, there were small amounts of different material which were assumed to have been ejected from the highlands to the south, perhaps in part by the impact which formed the crater Theophilus.

After the EVA the crew gathered items no longer needed, including the PLSS life support 'backpacks' used on the surface, and jettisoned them. The crew suits were hooked up to LM systems for life support while the cabin was depressurized during this procedure, and the jettison was seen by the TV camera which was still transmitting images. The first PLSS fell on the footpad and remained propped against the landing leg. The second fell flat on the ground nearby and may be visible in LRO images at the position shown in Figure 143B. A bag of other items followed, but its location is not discernable in TV or LRO images. Armstrong noted that the flag had moved slightly after the PLSS jettison, either under its own weight or because of gas pressure as the LM was depressurized. After repressurizing the LM the crew tried to rest, without much success given the cramped conditions and general excitement. Meanwhile Michael Collins was still trying to locate the LM on the surface as he flew overhead. After checking and preparing the LM for departure, the attitude control thrusters were briefly tested by firing them, moving the flag again.

The LM ascent stage launched from the lunar surface, leaving the descent stage behind, at 17:54 UT on 21 July after having spent 21.6 hours on the Moon. The LM rendezvoused with the orbiting CSM and docked at 21:34 UT. It was unloaded and then separated at 00:01 UT on 22 July and left in lunar orbit. It probably impacted at an unknown location near the equator within 1 to 4 months.

The Trans-Earth Injection (TEI) burn beginning at 04:55 UT on 22 July sent the spacecraft out of lunar orbit and back towards Earth. A trajectory correction burn was made several hours later on the same day. As the spacecraft approached Earth the CM separated from the SM at 16:21 UT on 24 July, and the SM burned up in the atmosphere. Apollo 11's Command Module dropped safely into the Pacific Ocean at 16:50 UT on 24 July after a total mission elapsed time of 195 hours, 18 minutes, 35 seconds. The splashdown location was 13° 19' N, 169° 9' W, about 600 km SSW of Wake Island and 24 km from USS Hornet, the recovery ship.

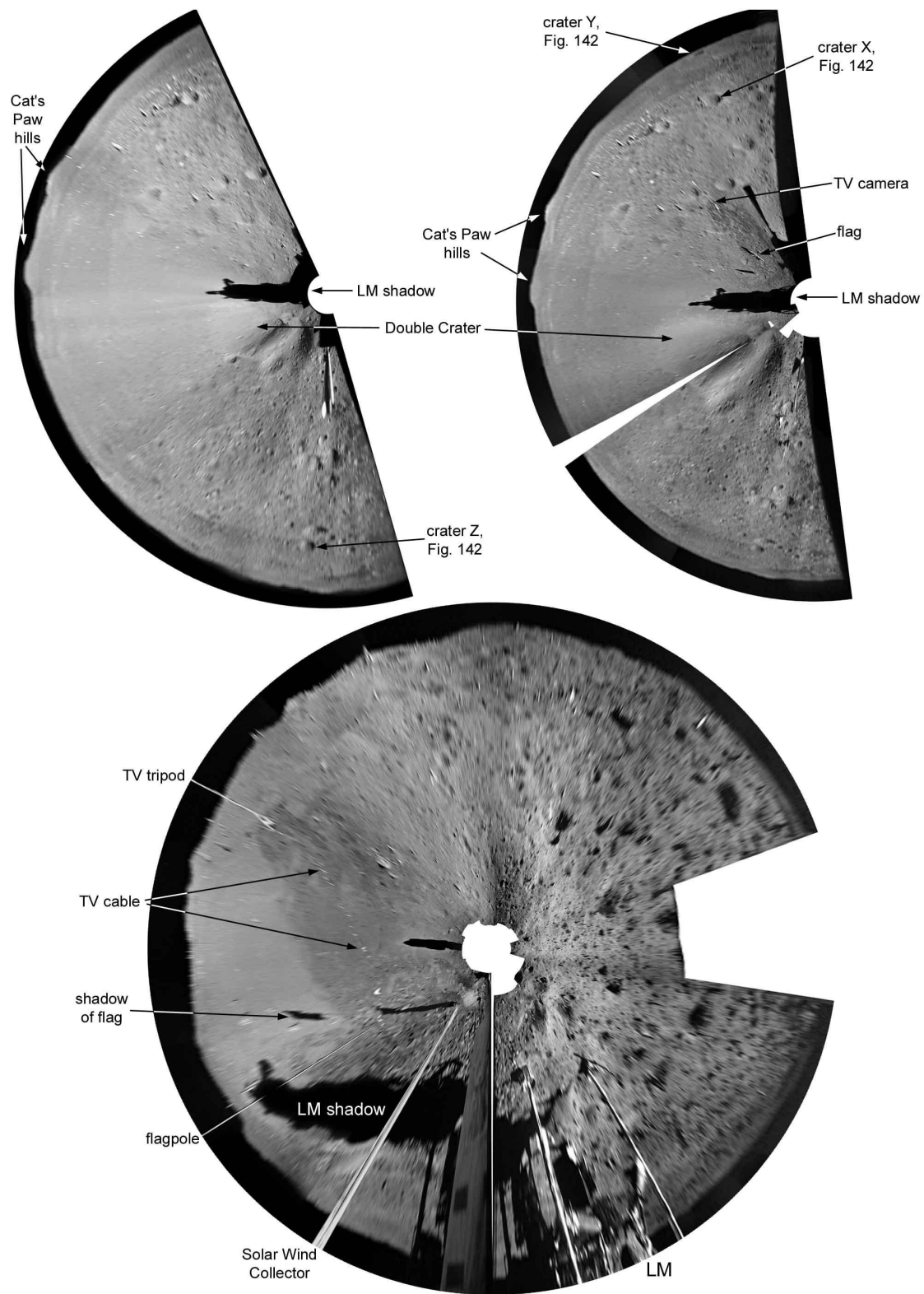


Figure 146. Reprojected Apollo 11 panoramas. A: view from LM windows before EVA. B: view from LM windows after EVA. C: panorama north of LM.

Figure 137A shows the five Apollo landing sites chosen for the first landing mission. Apollo 11 was directed to site ALS-2 in Mare Tranquillitatis, but launch delays could push the landing to Site 3 or Site 5 if necessary. Figure 141B shows the Apollo 11 prime landing ellipse, now enlarged to 20 km by 5 km. Several informal names are shown. They were given to landmarks which might be viewed during the descent to help locate the landing site within the ellipse. The center of the ellipse was the nominal target, but landing at any location would constitute a successful mission, unlike later landings which were required to land close to a specific target.

In 1970 the International Astronomical Union approved names for three craters near the Apollo 11 landing site to commemorate the crew. Normally, names of living people are not assigned to craters, but this exception and a few others (Figures 74A, 132A) were deemed acceptable. Craters previously known as Sabine B, D and E were now called Aldrin, Collins and Armstrong respectively (Figure 141A).

Figure 142 locates the landing site. There are small discrepancies between plotted landing ellipses in different documents, and the Apollo 11 landing ellipse in Figure 141B is taken from NASA graphic S-69-3715, included in the Apollo 11 Mission Report (MSC 1969a). The nominal landing point was the ellipse centre, close to the areas modelled at full size at Cinder Lake, near Flagstaff (Figure 140A) and near the hypothetical traverses shown in Figure 122B. Several informal names are shown on the maps.

Figure 143 shows surface activities at the landing site. Double Crater is prominent in the panoramas (Figure 145). Areas disturbed by footprints are shown in a darker tone in Figure 143A and can be seen in LRO images and surface images. The site maps here are based on LRO images and include information from various maps published in the Apollo 11 Preliminary Science Report (NASA, 1969), a U. S. Geological Survey map published by the Defense Mapping Agency in 1978, and maps on the Apollo Lunar Surface Journal website by Vlad Pustynski, Thomas Schwagmeier and Brian McInall.

Figure 144 is a mosaic of surface panoramas projected onto the surface and controlled by an enlargement of Figure 143. It shows the various sample collection areas. The contingency sample was collected by Armstrong soon after he set foot on the surface in case an emergency departure became necessary. The bulk samples were collected quickly from four areas to provide as much lunar material as possible. The documented samples were supposed to be collected with careful descriptions and before and after photographic records, so that the identities and lunar orientations of rocks would be known, but time did not permit proper documentation. Two cores, 10 and 13.5 cm deep, were obtained by hammering hollow tubes into the soil. The Apollo Lunar Surface Closeup Camera (ALSCC) was used to take stereoscopic pairs of photographs of small areas in the regions indicated in Figure 143B.

Apollo 11 surface photography is presented in Figure 145 in the form of panoramic views compiled by P. Stooke, and Figure 146 shows three of these projected into a circular format to help compare features with maps. Apollo 11 orbital photographic coverage is shown in Figure 147. High resolution images were taken along the ground track by both the crew and automated cameras. Oblique views showed areas north and south of the ground track. The candidate Hipparchus landing site was photographed very near the terminator. Lower resolution images were obtained as Apollo 11 left lunar orbit on the return journey. The spacecraft spent two days in orbit, during which the terminator moved about 25°, so the longitudinal extent of photography is about 205°, not 180°.

As the LM ascent stage lifted off to return to orbit, its exhaust ripped thermal blanket foil off the descent stage and blew fragments around. Late Apollo missions observed this with window-mounted cameras in the ascent stage and cameras on parked rovers. For Apollo 11 the ascent stage window camera started filming late and missed the debris event, but LRO images of the site show bright spots which may include parts of the foil blankets. Some rocks look similar, so a reliable inventory is not possible, but Figure 148 shows some fragments identified by Vladislav Pustynski, from the Apollo Lunar Surface Journal. Aldrin reported that the flag was blown over at liftoff, and a bright feature in some LRO images may be from the flag or its support bar on the ground, as suggested in Figure 143B, or from more of the thermal foil.

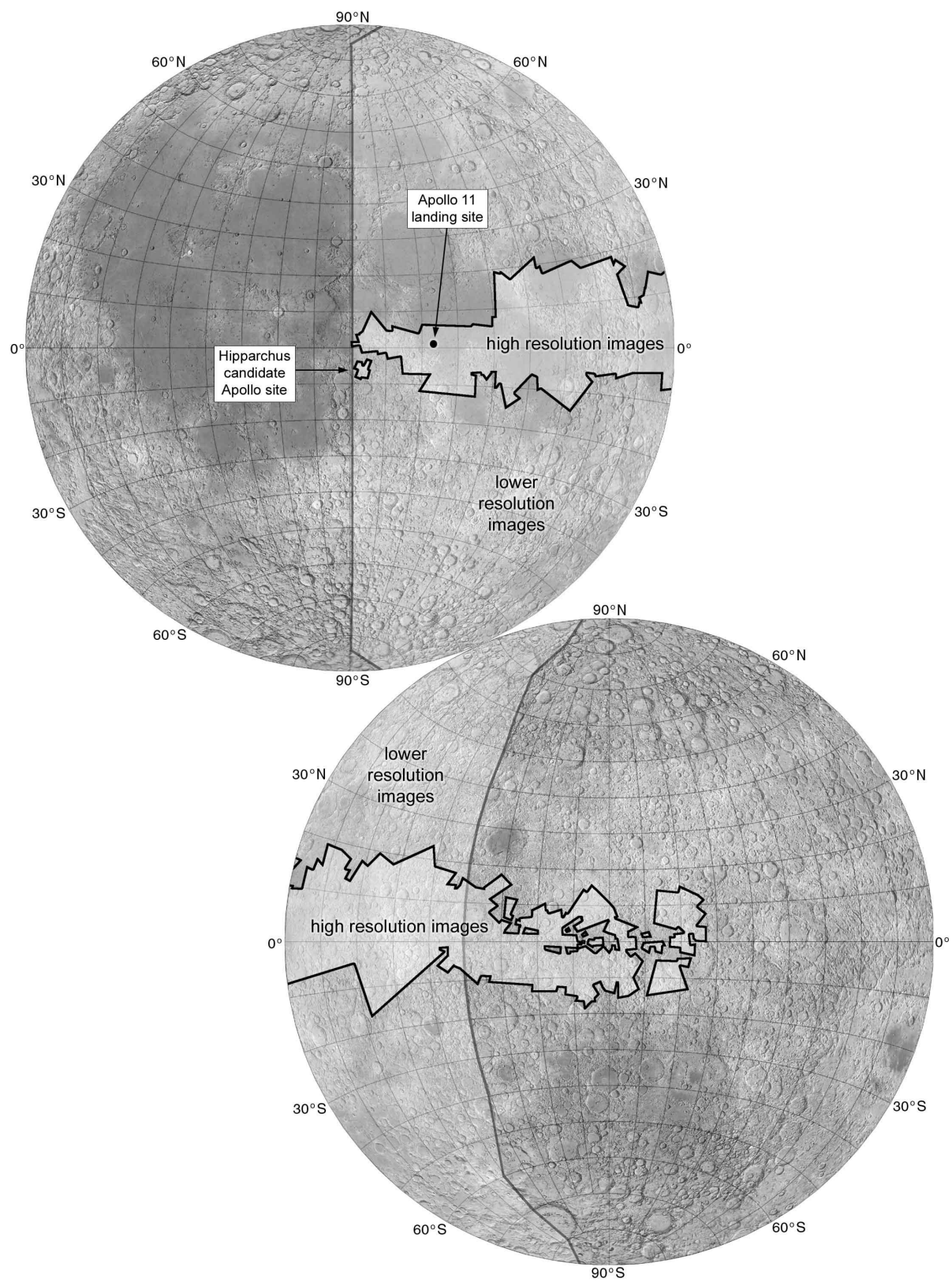


Figure 147. Apollo 11 photographic coverage.

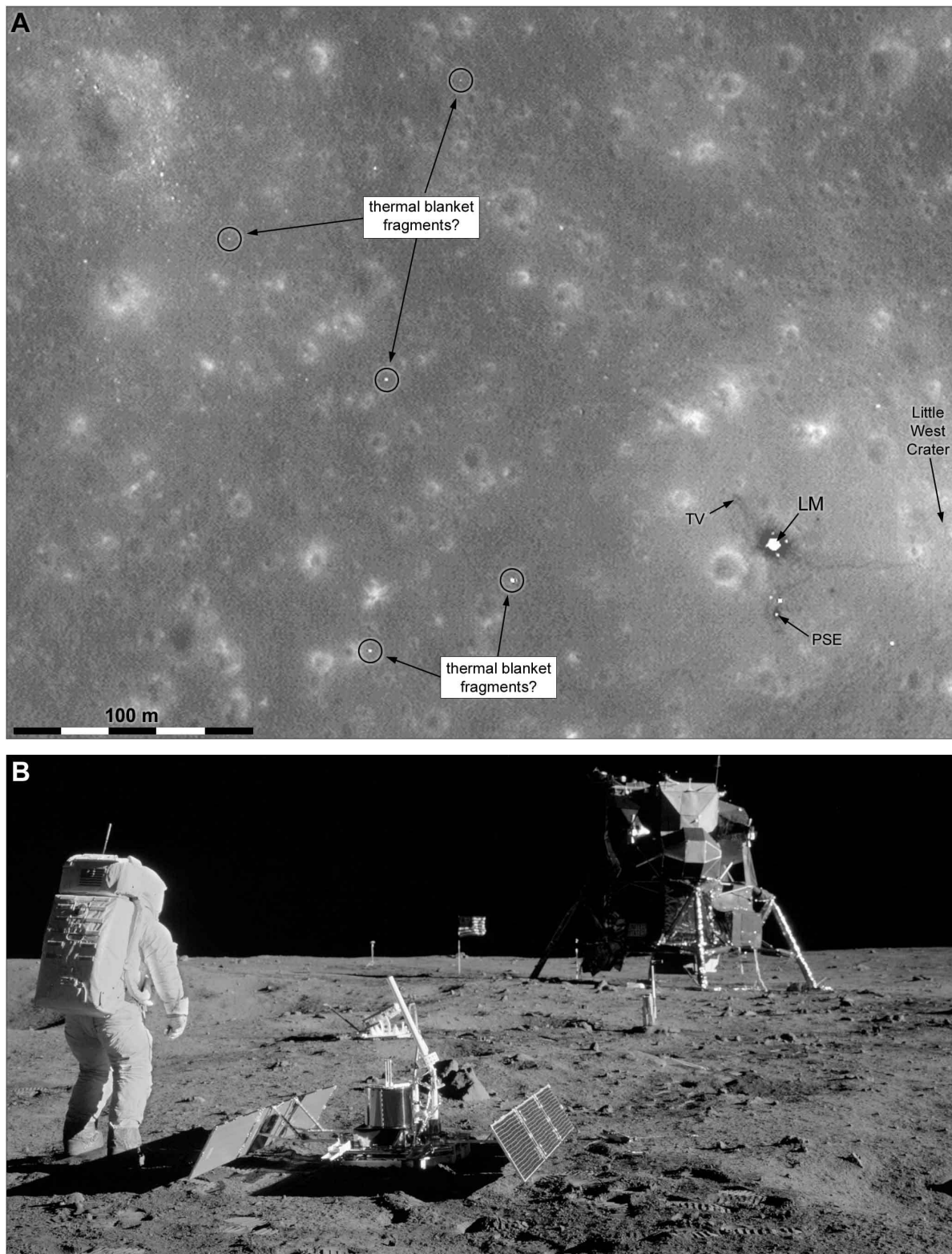


Figure 148. Apollo 11 thermal blanket fragments and surface view. A: bright spots in LRO image M109080308R suggested by Vladislav Pustynski (Apollo Lunar Surface Journal) to be thermal blanket fragments ejected at liftoff. B: Apollo 11 image AS11-40-5948 showing Aldrin standing beside the seismometer.

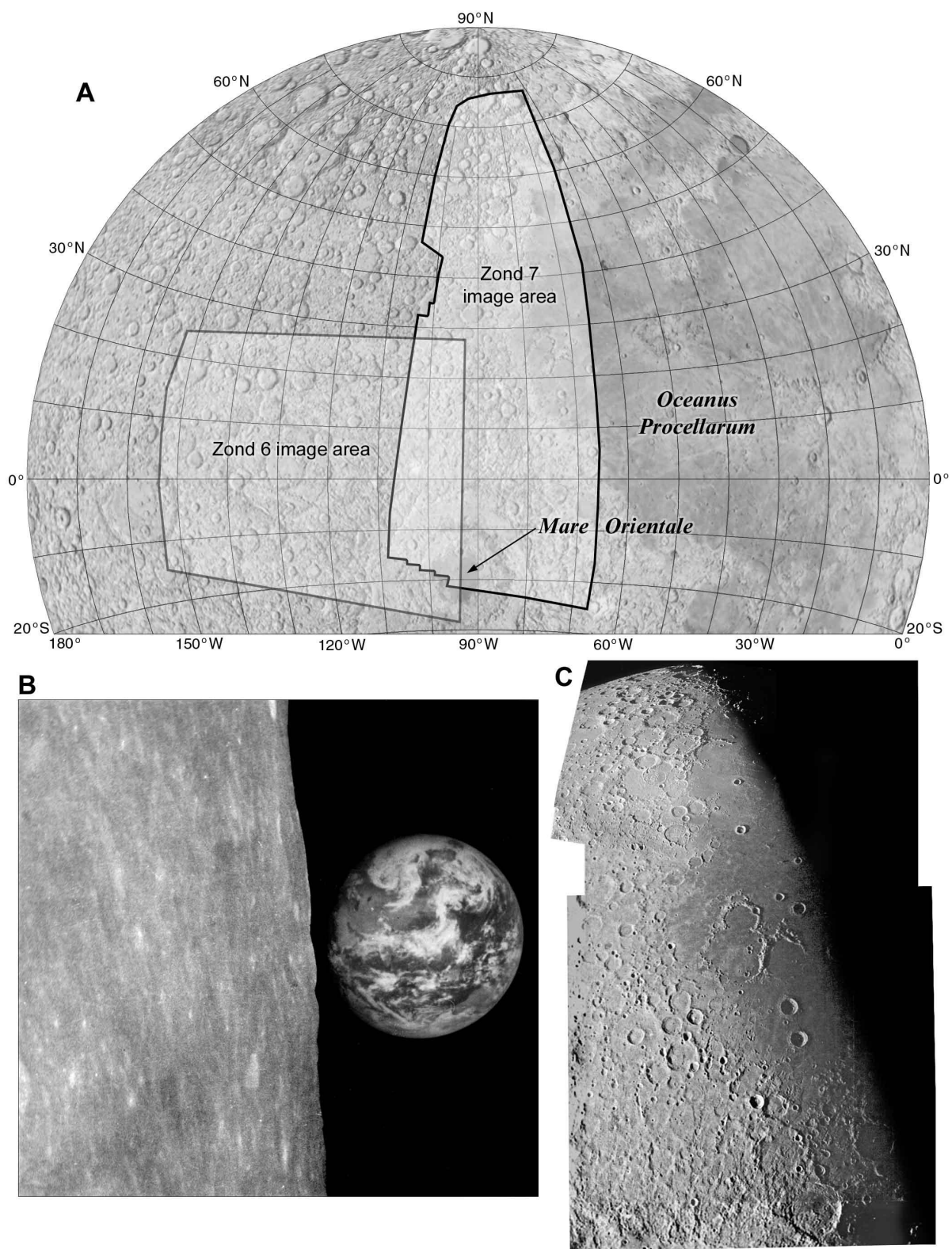


Figure 149: Zond 7 images and coverage map. A: area covered by Zond 7 images. The Zond 6 image area is also indicated. B: Earthset observed by Zond 7. C: mosaic by P. Stooke of most of the Zond 7 photo coverage.

NASA, 1969. *Apollo 11 Preliminary Science Report*. NASA SP-214. Scientific and Technical Information Division, Office of Technology Utilization, NASA. Washington, D.C.: National Aeronautics and Space Administration.
<https://www.nasa.gov/history/alsj/a11/a11psr.html>



07 August 1969: Zond 7

The Soviet Union's Zond 7 mission was a further test of systems required for cosmonauts to visit the Moon, similar to the missions of Zonds 4, 5 and 6. The 5979 kg spacecraft was launched from Baikonur at 23:48 UT, entered parking orbit, and then was placed on its translunar trajectory. The spacecraft looped around the Moon and reentered the Earth's atmosphere on 14 August, landing safely about 50 km from its pre-planned target south of Kustanai. This was the only fully successful flight of the lunar version of the Soyuz spacecraft, and the only one which would have returned its crew alive. A biology payload including four tortoises survived the flight, the first living things to travel to and from the vicinity of the Moon.

Like Zond 6, this mission obtained photography of Earth and the Moon (Figure 149). Earth photos were obtained on 9 August. On 11 August the spacecraft flew past the moon at a distance of 1985 km and conducted two picture taking sessions, obtaining Earthset views and 20 terminator images but, on this mission, no full-disk images. Zond 7 images extended Zond 6 coverage into the nearside. The original images were exposed on colour film and returned to Earth for processing. Those used here were provided by MIIGAiK.

Figure 149A shows the area covered by Zond 7 images, from an index map provided by K. B. Shingareva (MIIGAiK). The Zond 6 photo area is also indicated. The two images are an Earthset scene (Figure 149B) and a mosaic of most of the Zond 7 photo coverage by P. Stooke (Figure 149C).



23 August 1969: Group for Lunar Exploration Planning

ASSB had approved a sequence of landings at its last meeting, but GLEP now considered some minor changes which had become necessary as detailed mission plans were drawn up (Table 48).

Alternate lists were presented by Calvin H. Perrine and Dennis James, and after discussion GLEP approved a modified list. They also considered requirements for equipment and experiments, as shown in the notes section of Table 48. The choice of sites depended in part on when particular items (*e.g.* a rover) or capabilities (additional stay time permitting more EVAs) would be ready.

Table 48. GLEP site changes and equipment needs, 23 August 1969						
Launch date	Mission number	ASSB list	Perrine's list	James's list	GLEP modified list	comments
7/69	11 (G)	Site 2	Site 2	Site 2	Site 2	EASEP, PSE
11/69	12 (H1)	Site 3	Site 3	Site 3	Site 3	ALSEP, PSE
3/70	13 (H2)	Fra Mauro	undecided	Fra Mauro	Fra Mauro	HFE, PSE
7/70	14 (H3)	Censorinus	Rima Bode	Littrow	Rima Bode or Littrow	ALSEP
11/70	15 (H4)	Rima Bode	Fra Mauro	Descartes	Censorinus or alternate	ALSEP, PSE
4/71	16 (J1)	Tycho	Tycho	Tycho	Tycho	ALSEP, LRRR, HFE, PSE
7/71	17 (J2)	Copernicus	Marius Hills	Copernicus	Copernicus	rover, 4 or more EVAs, HFE, PSE
2/72	18 (J3)	Marius Hills	Copernicus	Rima Bode	Descartes	HFE, PSE, rover
7/72	19 (J4)	Descartes	Rima Prinz	Marius Hills	Marius Hills	rover, LRRR, HFE, PSE
12/72	20 (J5)	Rima Prinz	Descartes	Hadley Rille	Hadley Rille	rover, HFE, ASE, LRRR, 4 or more EVAs
Notes: For Apollo 16 to 20, the order of items in the comments reflects their priority. EASEP: Early Apollo Surface Experiment Package; PSE: Passive Seismic Experiment; ALSEP: Apollo Lunar Surface Experiment Package; HFE: Heat Flow Experiment; LRRR: Laser Ranging Retroreflector; EVA: Extravehicular Activity; ASE: Active Seismic Experiment. The GLEP minutes for this meeting refer to the Apollo 11 site as Site 9 (possibly a simple error) and the Apollo 12 site as Site 3, though Site 7 (Surveyor 3) had already been chosen with Site 5 as a backup.						



23 September 1969: Luna (Cosmos 300)

This was another attempted robotic soil return mission similar to Lunas 15 and 16, directed to a target in the same general area spanning Mare Fecunditatis and Mare Crisium. The spacecraft was stranded in low Earth orbit because of an upper stage malfunction and given a generic 'Cosmos' designation.



22 October 1969: Luna (Cosmos 305)

This spacecraft was another in the series of attempted robotic soil return mission similar to Lunas 15 and 16, and directed to a target in the same general area spanning Mare Fecunditatis and Mare Crisium. This spacecraft suffered the same fate as Cosmos 300.



16-17 October 1969: Group for Lunar Exploration Planning

This meeting took place over two days. Alternate landing sequences continued to be discussed as planning for the later landings continued. Numerous lists circulated and appeared in committee minutes. Table 49 is a composite of several lists from the minutes of this GLEP meeting. The numerous variant lists at this time complicate the process of tracking landing site selection. Figure 206 illustrates the variety of mission proposals by mapping EVA routes and sample sites from a variety of sources.

Additional sites were also discussed at this meeting, including Hyginus, Lassell, Hipparchus, Abulfeda and Alphonsus, all of which had proponents and opponents. Harold Masursky opined at this meeting that “Hipparchus is the least interesting site on the Moon”, and indeed it was dropped from consideration as its goals could be met elsewhere. Finally, Apollo 13 site planning continued as summarized in Table 50. At this time a backup landing site was still required for Apollo 15, and Site 6R was the preferred option. This was near Surveyor 1 but adjacent to a hill on the rim of the flooded crater Flamsteed P (Figure 112D).

Table 49. Apollo sequence alternatives from GLEP minutes, 16-17 October 1969

Mission	Prime site	Alternative 1	Alternative 2	Alternative 3		New GLEP list (5)
12 (H1)					Sites 5 or 4	
13 (H2)	Fra Mauro	Alphonsus (1)	Alphonsus (1)	Fra Mauro (1)	Fra Mauro Formation (2)	To be determined
14 (H3)	Littrow	Littrow	Littrow	Littrow	Rima Bode II (3)	Fra Mauro
15 (H4)	Censorinus	Fra Mauro	Fra Mauro	Censorinus	Censorinus NW	Littrow
16 (J1)	Descartes	Censorinus	Censorinus	Descartes	Copernicus Peaks	Censorinus
17 (J2)	Marius Hills	Marius Hills	Marius Hills	Marius Hills	Marius Hills (4)	Marius Hills
18 (J3)	Copernicus	Copernicus	Davy Rille	Davy Rille	Tycho Rim	Descartes
19 (J4)	Hadley	Hadley	Hadley Rille	Hadley Rille	Rima Prinz I	Hadley Rille
20 (J5)	Tycho	Tycho	Copernicus	Copernicus	Descartes	Copernicus
Mission	Alternative lists					
13 (H2)	Alphonsus or Hipparchus	Alphonsus or Hipparchus	Littrow	Alphonsus	Hyginus, Rima Bode or Davy Rille	
14 (H3)	Littrow	Littrow	Fra Mauro	Littrow	Fra Mauro	
15 (H4)	Censorinus (Fra Mauro)	Censorinus	Censorinus		Lassell	
16 (J1)	Mid-Serenitatis (Censorinus)	Tycho	Descartes, Rima Bode or Hyginus	Polar orbit mission	Censorinus	
17 (J2)	Copernicus	Copernicus	Marius	Marius	Copernicus central peak	
18 (J3)	Marius Hills	Davy Rille	Copernicus		Descartes	
19 (J4)	Davy Rille (Tycho)	Marius Hills	Hadley	Tycho	Marius Hills	
20 (J5)	Hadley/Apennines	Hadley/Apennines	Tycho, Rima Bode or Hyginus	Gassendi & a telescope	Hadley/Apennines	

Notes: (1): Hyginus is an alternate if Alphonsus or Fra Mauro are not possible. (2) Future Apollo 13/14 site (Imbrium ejecta), not the site shown in Figure 148, and to be considered for H3 if not visited on H2. (3): consider for H4 if not visited on H3. (4): Marius before Tycho, in case the rover is not available for J2. (5) Alternatives include Tycho and Lalande.

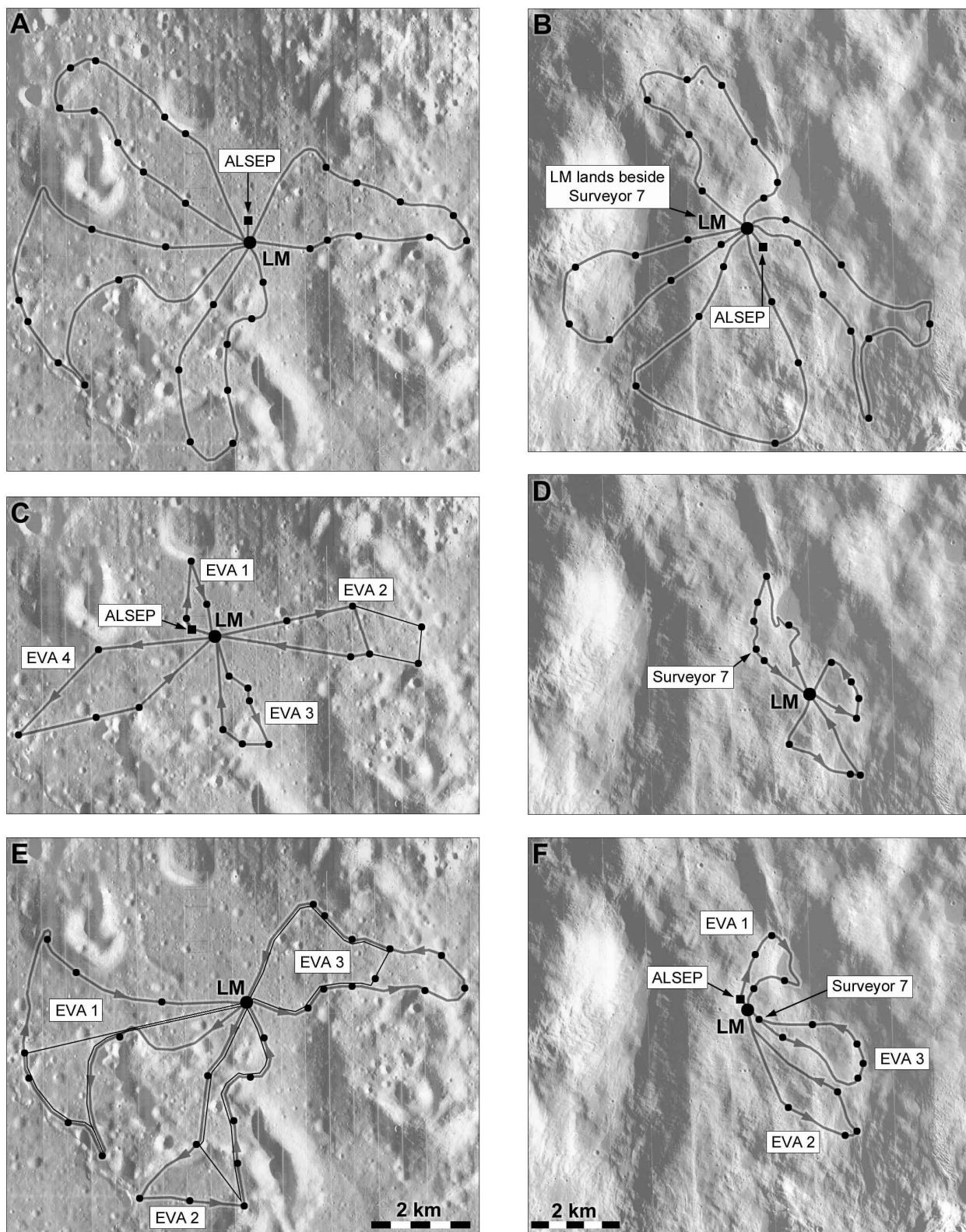


Figure 150. Alternative EVA plans, part 1. Left column: Marius Hills. Right column: Tycho.

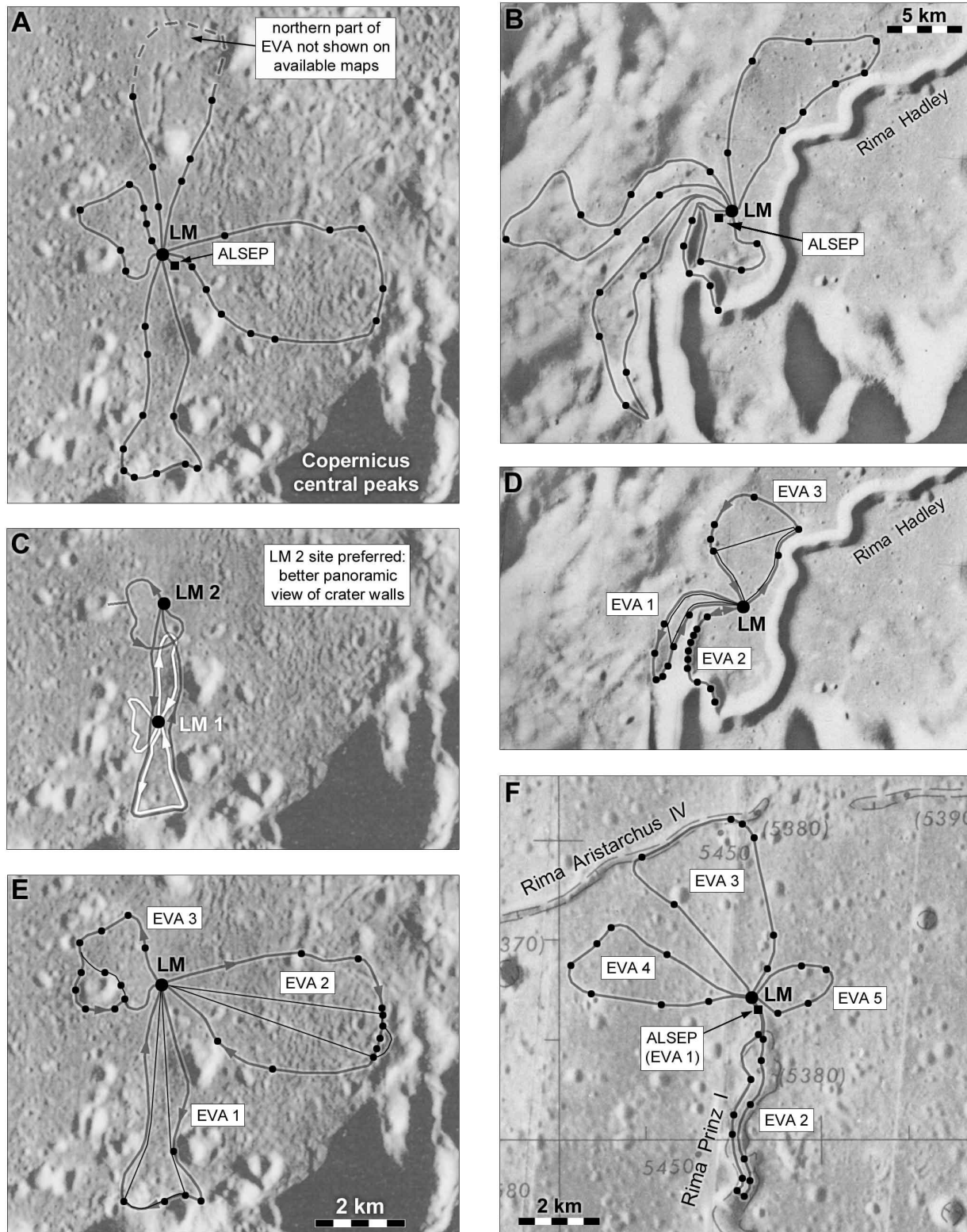


Figure 151. Alternative EVA plans, part 2. Left column: Copernicus. Right column: Rima Hadley and Rima Prinz.

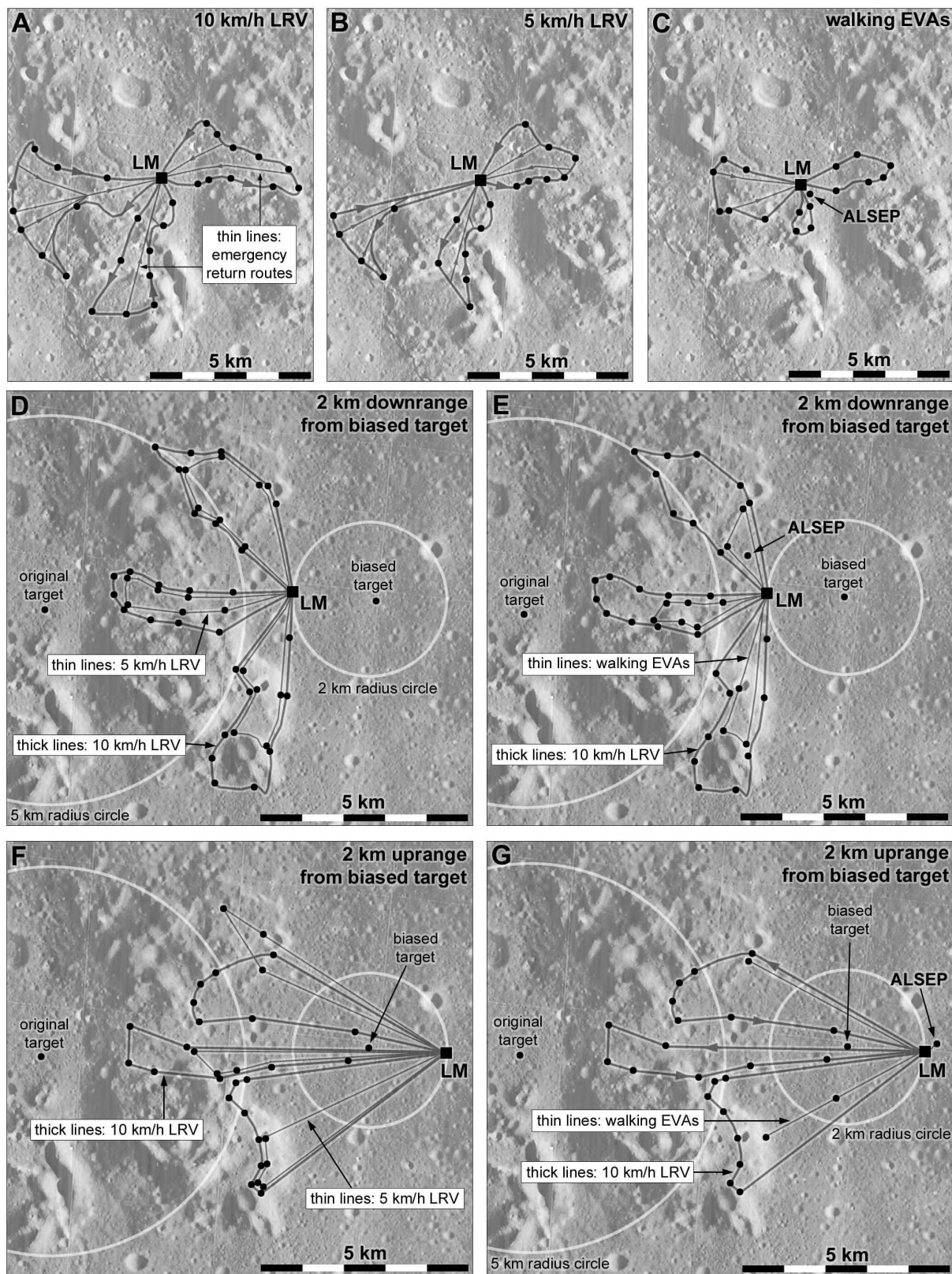


Figure 152. Alternative EVA plans, part 3. Marius Hills plans from Benjamin *et al.* (1969).

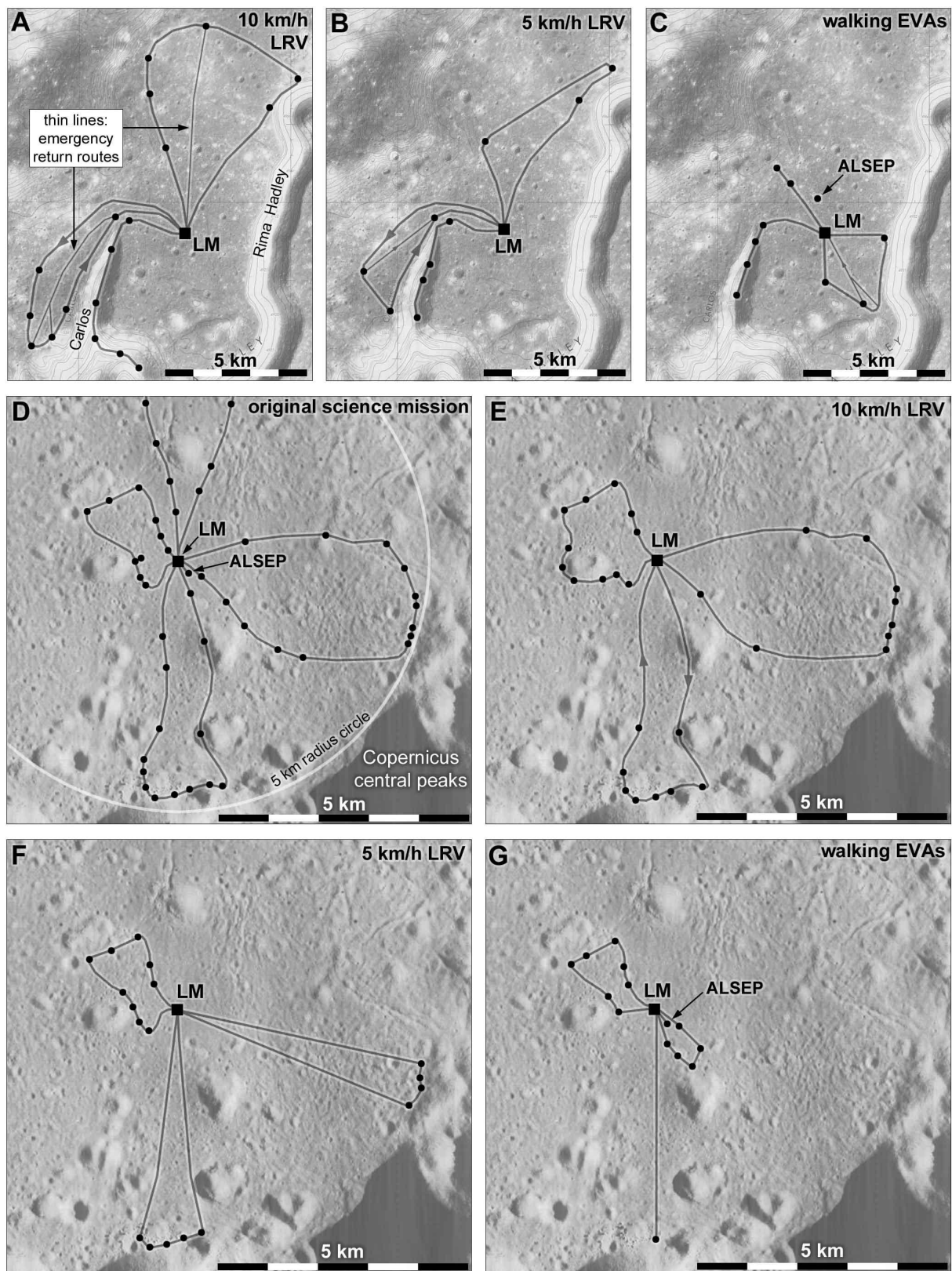


Figure 153. Alternative EVA plans, part 4. Hadley and Copernicus plans from Benjamin *et al.* (1969).

Figures 150-153 show several alternative EVA plans for some of the possible late Apollo sites. In Figure 150 the sites are Marius Hills (left column) and Tycho (right column). In Figure 150E the Marius EVAs include shorter optional routes (thinner lines) if time or resources were restricted. Sample sites are shown as dots on the EVA routes. In Figure 151 the sites are Copernicus peaks (left column) and Hadley-Apennine and Rima Prinz I (right column). Figure 151C shows two sets of EVAs for different landing points. Figures 151D and 151E show abbreviated routes as thinner lines. EVA 1 at Rima Prinz I would be for ALSEP deployment.

The sources for the various EVA plans shown in Figure 150-152 are as follows: Bellcomm presentation to MSC, 4 September 1969 (150A, 150B, 151A, 151B); Transparencies prepared by USGS Flagstaff for the NASA ad hoc [site selection] committee, August 1969 (150C, 150D, 151C, 151F); Shayler, 2002 (150E, 150F, 151D, 151E); The Bellcomm and USGS materials are from the Branch History collection at Flagstaff.

Another Bellcomm study (Benjamin *et al.*, 1969) described EVA plans for later Apollo missions which would carry a rover. Mission plans were being developed assuming that the rovers would work properly but alternative plans would be needed if the rover failed partially or wholly, or if the landing missed its target. A complete rover failure would require walking EVAs to recover as many mission goals as possible, and a rover with reduced speed or range would require shortened routes. The study examined sites at Hadley-Apennines, south of the later Apollo 15 landing area, Marius Hills and Copernicus Peaks, and included a study of offset (biased) landings at Marius Hills. The landing site coordinates were 14° 36' N, 56° 34' W (Marius Hills), 14° 45' N, 56° 09' W (Marius Hills Biased), 24° 47' N, 2° 27' E (Hadley-Apennines) and 9° 52' N, 19° 55' W (Copernicus Peaks). The study began with the science plans illustrated in Figure 152A, 153A and 153D and identified shorter traverses, emergency return routes and walking traverses. Figures 152 and 153 illustrate these plans. They are indicative of the many studies undertaken to arrive at final mission plans for the Apollo landings.

Traverses at the three landing sites were studied for the case of a rover with a speed limited to 10 km/hour and 5 km/hour, and for walking EVAs with an assumed speed of 4 km/hour. Each study allowed 15 minutes per site for sampling or other work. At Hadley South the original science mission included ALSEP deployment and four long EVAs into the surrounding plains. Two of them included visits to the rille rim for sampling and imaging of the walls, and one included a long descent into the rille via the north end of the linear depression at its head, assumed to be the original eruption vent, where shallow slopes were anticipated. The alternative rover missions would not deploy an ALSEP in this study, significantly reducing their science value. The 10 km/hour rover mission would include three EVAs designed to achieve some of the objectives of the full mission with shorter traverses. The excursion into the depression would not reach the rille itself, and opportunities to sample the ancient Apennine Mountains materials west of the landing site would be lost in the alternative missions.

Emergency return routes for two of the EVAs were also illustrated. The 5 km/hour rover would shorten the traverses even more but would still allow two views of the rille walls and a short excursion into the depression which would not reach the rille. Walking EVAs would be shorter still but would provide one view of the rille walls and short excursions into the plains and the depression, and an ALSEP would be deployed near the landing site. Overall the science results were significantly degraded by every option other than a full mission.

The original mission at Marius Hills included four EVAs with visits to three of the volcanic domes around the landing site and one EVA to a wrinkle ridge west of the site, as well as an ALSEP deployment north of the LM. The 10 km/hour rover mission would have three EVAs, two to the domes and one to the wrinkle ridge, achieving essentially all the goals of the mission except that an ALSEP would not be deployed. The 5 km/hour rover would also achieve the same goals with significantly shorter routes and fewer stops. A walking mission would abandon the wrinkle ridge objective but would still allow short traverses to two domes and an ALSEP deployment.

The alternative landing sites study replaced the usual Marius landing site in the middle of a cluster of volcanic domes (Figure 152A) with a 'biased site' east of the domes. The study then assumed that a landing might occur 2 km uprange (east) or 2 km downrange (west) of the biased target (Figures 152D-G). At the downrange site the 10 km/hour rover could easily reach three domes. The 5 km/hour rover could reach two of the three domes, and a walking EVA could do the same but with more limited access to the domes. The walking mission would also include an ALSEP deployment. The uprange site would offer more limited access to the main science targets. A 10

km/hour rover could still reach the domes but with less time for science stops at that distance. The 5 km/hour rover could still reach one or two domes, with even more limited time for study, but the walking EVA would barely be able to reach a dome.

At Copernicus the original mission (Figure 153D) had four EVAs, two to different parts of the central peak complex and two into the impact melt-covered plains north and west of the landing site. An ALSEP would also be deployed southeast of the lander. A 10 km/hour rover (Figure 153E) would make three EVAs, similar to three of the full traverses but with fewer stops for sampling. The long traverse north of the LM would be dropped but the two central peak visits would be retained. A 5 km/hour rover (Figure 153F) could still visit both central peak sites, briefly and with limited stops, and would also make a short looping traverse in the plains. The walking mission (Figure 153G) would be more constrained, with an ALSEP deployment and two short excursions into the plains, but it would just manage to fit in a long walk to the central peak south of the LM and back, with a single sampling stop.

Table 50. Evaluation of Apollo 13 (H-2) Landing Site Candidates

Landing Site	Accessible in March 1970	Launch date in March 1970	Recycle time to Site 6R (Flamsteed)	Bootstrap imaging possibilities
Fra Mauro	yes	12	2 days	Censorinus and Lalande
Littrow	yes	9	5 days	Hadley
Hyginus	yes	10	4 days	Censorinus (oblique), Copernicus
Rima Bode	yes	11	3 days	Censorinus (marginal), Copernicus
Alphonsus	yes	11	3 days	Censorinus and Lalande
Hipparchus	yes	11	3 days	Censorinus and Lalande
ALS 3	yes	11	3 days	Censorinus and Lalande

The Lalande site at 4° 55' S, 8° 30' W had not been included in any of the earlier evaluations of possible sites, though a mare site near it had been included in the Apollo Working Paper 1100 list in 1963 (Table 7, Figure 18). It lay on the outer southern rim of Lalande and would provide ejecta including highland material probably excavated from Imbrium. The site is illustrated in Figure 154A.

At about this time the Censorinus site was also being reassessed (MSC, 1970). The landing sites considered previously (Figure 113H) were close to the crater rim, but the density of large blocks might be too great for a safe touchdown. Two sites more distant from the crater were chosen as alternatives (Figure 154B).

On the other hand, Censorinus had been favoured initially for being one of the few small fresh impacts in highland materials in the narrow Apollo zone. There might be other more interesting fresh impact sites at higher latitudes, reachable by Apollo once the free return constraint was dropped. Lockheed Electronics Company (1969) looked for alternatives in a report presented to MSC on 3 October. The report identified 24 small fresh highland craters similar in appearance to Censorinus and suitable as possible landing sites, based on a survey of Lunar Orbiter 4 images of the nearside (Table 51, Figures 154C-F). Many of them offered useful bootstrap imaging possibilities to help certify future sites. The sites ranged as far north as northern Mare Imbrium, as far south as southern Mare Humorum and westwards into the highlands west of Oceanus Procellarum. None of them were considered further, and since Censorinus was eventually dropped as a target no similar crater was investigated by Apollo. The most comparable target was North Ray crater at the Apollo 16 site, significantly smaller than any of these at 950 m diameter.

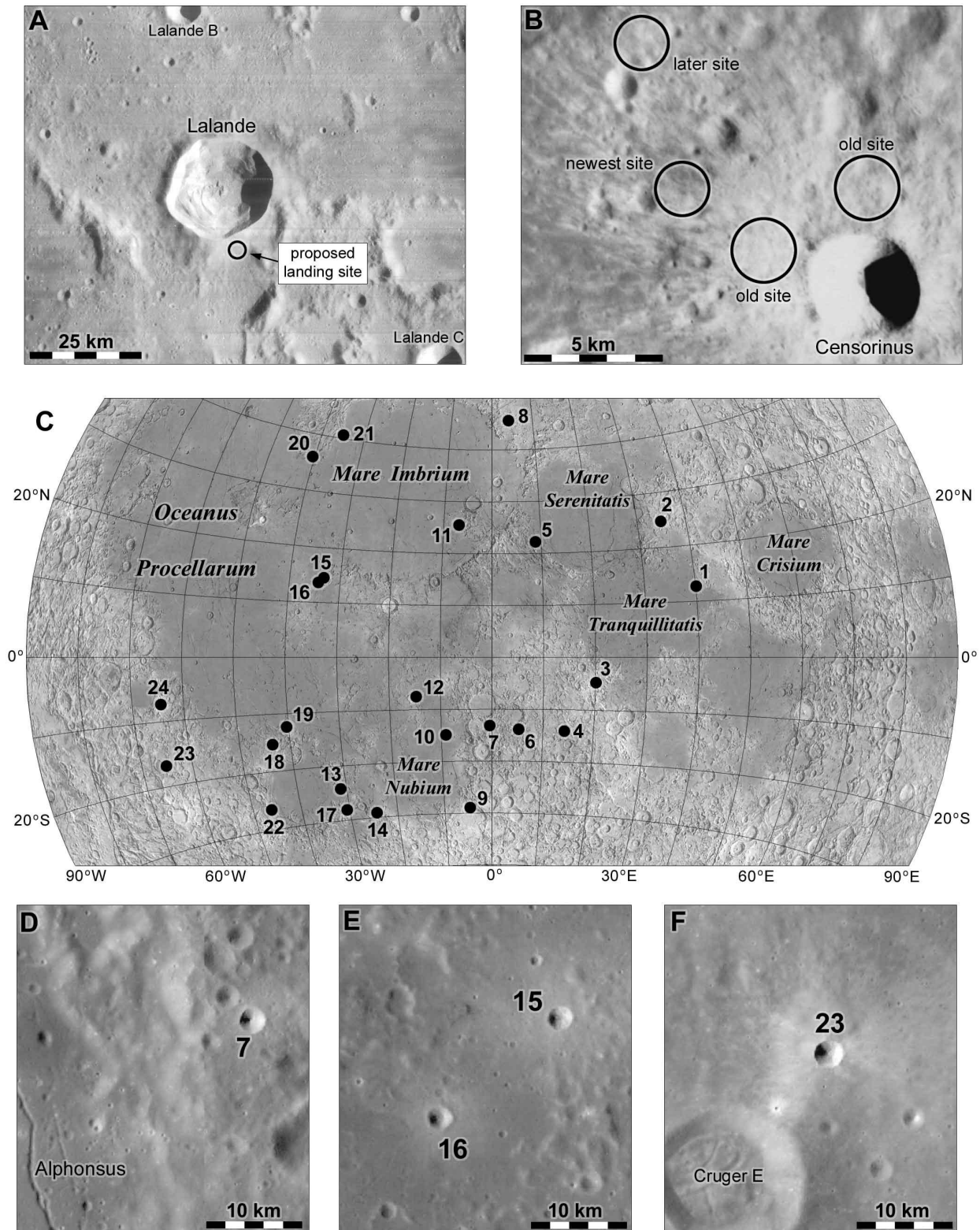


Figure 154. Alternative Apollo sites, October 1969. A: Lalande site (Table 50). B: Alternative sites at Censorinus from the October GLEP meeting. C: Alternatives to Censorinus (Table 51). D, E, F: LRO wide angle mosaic images of four representative sites from Table 51.

Table 51. Censorinus alternatives identified by Lockheed, 3 October 1969

Site	Comments	Diameter (km)	Location	Bootstrap options
1	Highland/mare boundary near Lyell crater	2.0	12° 40' N, 40° 30' E	H, M
2	On rim of Römer R crater	2.2	24° 25' N, 34° 00' E	H
3	Highland plains near Alfraganus	2.0	5° 10' S, 20° 35' E	A, M
4	On plains in floor of Abulfeda crater	1.5	13° 45' S, 14° 00' E	A, M
5	On plateau overlooking Mare Serenitatis	2.0	21° 43' N, 8° 53' E	L, H, M
6	On outer rim of Albategnius crater	2.2	13° 46' S, 5° 05' E	A, M
7	On east rim of Alphonsus crater	3.0	12° 50' S, 0° 46' W	A, M
8	Cassini K, among hills east of Montes Alpes	3.5	45° 05' N, 4° 05' E	(none)
9	Regiomontanus CA, on floor of ancient crater	3.9	29° 06' S, 5° 00' W	T
10	Between Lassell C and Lassell G	2.5	14° 37' S, 9° 06' W	A, M
11	Archimedes E on 'Apennine bench'	2.9	24° 58' N, 7° 12' W	H, L, M
12	On outer rim of Parry crater	3.7	7° 40' S, 14° 45' W	A, L, F, M, C
13	Mare Humorum border near Hippalus crater	2.3	23° 52' S, 31° 04' W	T, A
14	Edge of Mare Nubium near Mercator crater	2.3	29° 05' S, 24° 05' W	A, T
15	Hilly area near Tobias Mayer site	2.4	14° 35' N, 32° 36' W	A, M
16	Hilly area near Tobias Mayer site	2.4	14° 16' N, 32° 58' W	A, M
17	Mare Humorum border near Campanus crater	2.0	28° 05' S, 30° 40' W	T, A
18	West of Gassendi crater	2.6	16° 26' S, 42° 48' W	A, L
19	On a ridge on outer rim of Letronne crater	3.8	11° 59' S, 39° 47' W	A, L, F, C
20	On Gruithuisen γ dome (volcanic?)	2.7	36° 35' N, 40° 34' W	H
21	On Promontorium Heraclides**	2.6	40° 46' N, 35° 48' W	H
22	On plains in old crater west of M. Humorum	2.1	26° 36' S, 47° 26' W	T
23	East of Cruger crater	3.0	17° 00' S, 64° 57' W	L, C, F
24	Plains between outer rings of Grimaldi basin	2.6	7° 58' S, 64° 37' W	L, F, C, A*, TM

Bootstrap options: landing sites which could provide orbital images of the candidate crater suitable for site certification and EVA planning. **Bold** indicates vertical or near-vertical viewing, preferred for mapping. A: Alphonsus (A* - misprint in original report; Alphonsus probably intended); C: Copernicus; F: Fra Mauro; H: Hadley/Apennine; L: Littrow; M: Marius Hills; T: Tycho; TM: Tobias Mayer.

** Crater 21: the report shows this crater on a map as reported in this table, but in a separate annotated Lunar Orbiter 4 image it indicates a 5 km diameter crater at about 40° 50' N, 36° 05' W. This was probably a mistake.

Benjamin, P., Bottomley, T. A., Head, J. W. and Yates, M. T., 1969. *Evaluation of Mobility Modes on Lunar Exploration Traverses: Marius Hills, Copernicus Peaks and Hadley-Apennines Missions*. Bellcomm report TR-69-340-4, NASA CR-108134, 14 November 1969.

Lockheed Electronics Company, 1969. *Lunar exploration: highland "impact" crater study*. Technical Working Paper LEC/HASD No. TWP 69-033 (LEC Document 648 D.21.033), 3 October 1969.

Shayler, D. J., 2002. *Apollo: the lost and forgotten missions*. London: Springer-Verlag.



30 October 1969: Apollo Site Selection Board

The Board considered the various GLEP lists just described, especially the ‘Prime Site’ column in Table 49 which originated from MSC. Hadley was considered to give a better view of a sinuous rille than Rima Prinz I, so Hadley was retained and Prinz dropped from consideration. Descartes and Hadley Rille were readily accessible, and the Marius site was available for only two months each summer, but Copernicus and Tycho were difficult to reach.

Descartes, Hadley, Davy and Censorinus required further photography, which would have to come from earlier Apollo flights. Since Littrow could provide this ‘bootstrap’ photography for Hadley it was preferred over the otherwise comparable site at Rima Bode I. Tycho was assigned the last Apollo flight to leave time to address the accessibility issues. The Board finally settled on the prime and alternative lists in Table 52 for planning purposes.

Table 52. Apollo landing sites approved by ASSB, 30 October 1969			
Mission	Prime site	First launch opportunity	Alternative site
H-2	Fra Mauro	12 March 1970	Hyginus
H-3	Littrow	8 July 1970	Littrow
H-4	Censorinus	30 October 1970	Fra Mauro
J-1	Descartes	29 March 1971	Censorinus *
J-2	Marius Hills	30 July 1971	Marius Hills
J-3	Copernicus	19 February 1972	Davy Rille
J-4	Hadley	14 July 1972	Hadley
J-5	Tycho	7 February 1973	Copernicus
Notes: The alternative list would apply if Fra Mauro was delayed and Tycho was dropped. * Lalande was another alternative for Censorinus.			

The Board also considered the landing site for Apollo 13. Fra Mauro would only be acceptable if Apollo 12 achieved a pinpoint landing. For a launch in March 1970, Fra Mauro was the prime target and no suitable backup was available. For a launch in April 1970 Site 6R (Flamsteed hill, also called Flamsteed ring) would serve as a backup. If Fra Mauro was found unacceptable, Hyginus would be the target, with Site 6R as backup.



14 November 1969: Apollo 12

This was the second human landing on the Moon. NASA’s Apollo 12 was intended to demonstrate the ability to land within walking distance of a specified target, which would be essential for sophisticated geological exploration on future landings. The crew were Commander Charles ‘Pete’ Conrad Jr. (also flew on Gemini 5 and Gemini 11, and later Skylab 2), Command Module Pilot Richard F. Gordon (Gemini 11) and Lunar Module Pilot Alan L. Bean (also flew on Skylab 3). The backup crew were David R. Scott, James B. Irwin and Alfred M. Worden. The CSM call sign was Yankee Clipper, the LM was Intrepid.

Apollo 12 launched from Pad 39A at Cape Canaveral at 16:22 UT on 14 November 1969. Just 36 seconds after launch, and again 16 seconds later, the Saturn V rocket was struck by lightning, but the only effect was a momentary power outage. The spacecraft reached a parking orbit after 11.75 minutes and its health was checked carefully. Then at 19:15 UT, after 1.5 orbits, the 5.75 minute SIVB upper stage translunar injection burn began. 25 minutes later the CSM separated from the S-IVB, turned, and docked with the LM at 19:49 UT.

The SIVB was placed in a distant Earth orbit with a 43 day period instead of the intended solar orbit due to an instrument error. An unexpected postscript to this event unfolded when an apparently asteroidal object, J002E3, was detected orbiting Earth on 3 September 2003 by Canadian amateur astronomer Bill Yeung, observing in El Centro, California. Its trajectory suggested it had been captured from solar orbit. Spectroscopy indicated a painted surface similar to a Saturn rocket. Orbit analysis suggests that the Apollo 12 SIVB completed 9 or 10 Earth orbits after launch, then passed through the L1 Sun-Earth Lagrange point where terrestrial and solar gravity are about equal, and slipped into solar orbit in March 1971. After 33 solar orbits and 31 Earth years it again passed through the L1 region in April 2002 and became a temporary satellite again. Six orbits later it slipped through the same region and into solar orbit in June 2003. This scenario will probably repeat several times until the SIVB meets its ultimate fate of hitting Earth or the Moon.

The LM was checked out during translunar cruise. A trajectory correction was made at 02:15 UT on 16 November. Another burn at 03:47 UT on 18 November put Apollo 12 into its initial lunar orbit, which was circularized after two orbits. Conrad and Bean separated the LM from the CSM at 04:16 UT on 19 November, began the descent at 05:47 UT, and landed at Site 7 (3.013° S, 23.422° W) in Oceanus Procellarum at 06:54 UT. Conrad and Bean performed two EVAs, the first on 19 November and the second on 20 November, during which an Apollo Lunar Surface Experiments Package (ALSEP) was set up, 34.4 kg of lunar material were collected, numerous photographs were taken, and parts were removed from Surveyor 3 for return to Earth.

The LM ascent stage lifted off from the Moon on 20 November at 14:25 UT after 31.5 hours on the surface, and docked with the CSM at 17:58 UT. After transferring samples and equipment to the CSM, the ascent stage was jettisoned at 20:21 UT and deliberately crashed on the lunar surface at 22:17 UT to create an artificial seismic signal for the ALSEP seismometer (Figures 166, 167). The trans-Earth injection burn began at 20:49 UT on 21 November, and a trajectory correction was made on 22 November. On 24 November the crew witnessed an eclipse of the Sun by Earth (they passed through the Earth's shadow) 50,000 km from Earth and only four hours before their re-entry. The CM separated from the SM at 20:29 UT on 24 November and splashed down at 15° 47' S, 165° 9' W in the Pacific Ocean near Samoa, 6.9 km from the recovery ship USS Hornet, at 20:58 UT. The whole mission lasted 244.6 hours. The Apollo 12 Command Module is now on display in the Virginia Air and Space Center, Hampton, Virginia.

Apollo 12 carried a 70-mm Hasselblad electric camera, two Hasselblad data cameras, two 16-mm Maurer automated cameras, one 35-mm lunar surface closeup camera for stereoscopic photography, and a four-camera, multispectral experiment to photograph potential future landing sites (Fra Mauro, Descartes, Theophilus) from orbit. The photographs included 1584 70-mm frames, 69519 16-mm frames, 15 stereoscopic pairs, and 552 frames of photography from the multispectral system. Parts returned from Surveyor 3 showed some effects of exposure to the lunar environment. Samples of lunar material showed that the mare surface in this area consisted of basalt lavas erupted about 3.2 billion years ago, four hundred million years younger than the Apollo 11 samples.

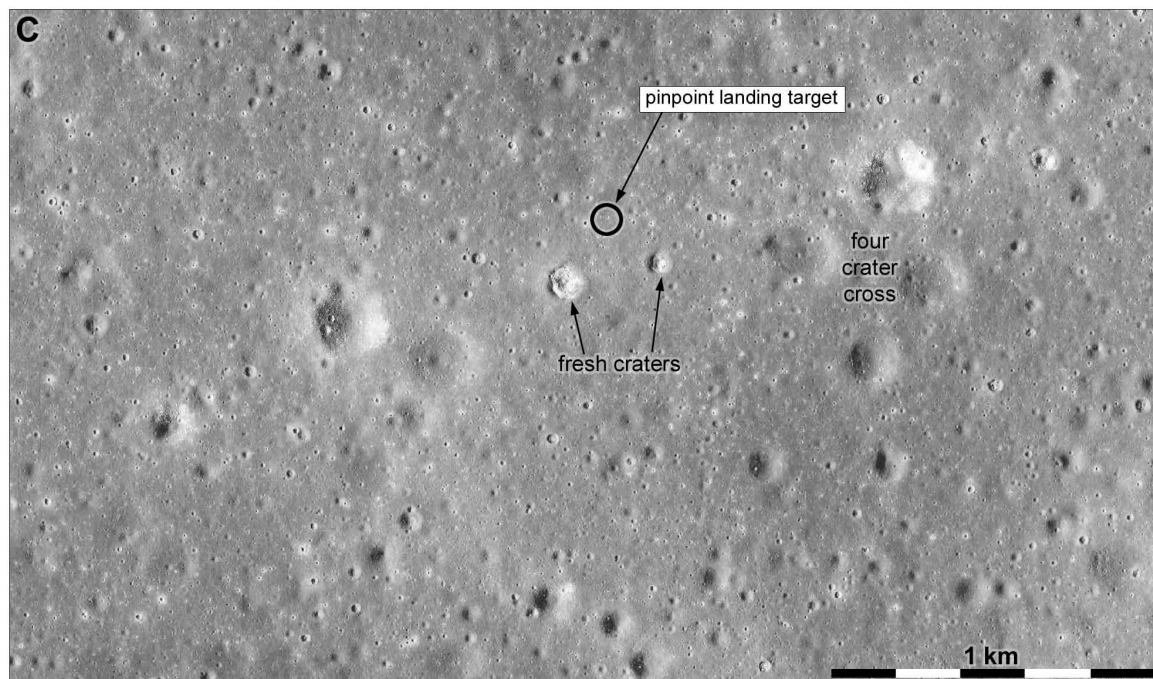
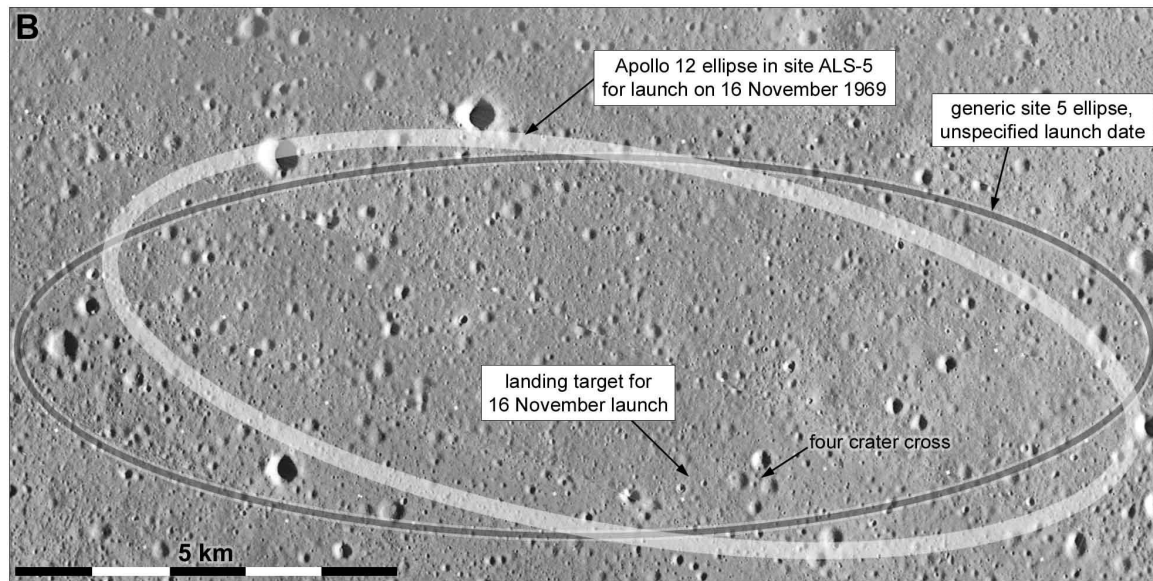
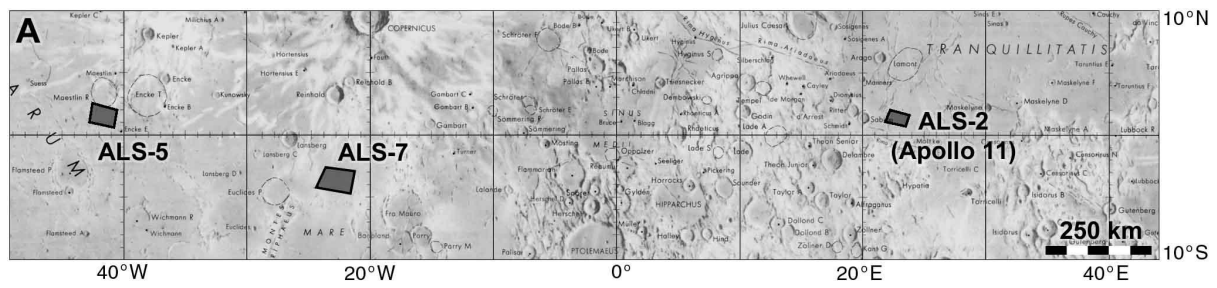


Figure 155. Apollo 12 landing and backup sites. A: Apollo 11 and 12 landing sites. ALS-7 is the Apollo 12 site, ALS-5 is the backup site. B: Apollo 12 backup ellipse. C: Apollo 12 backup landing site.

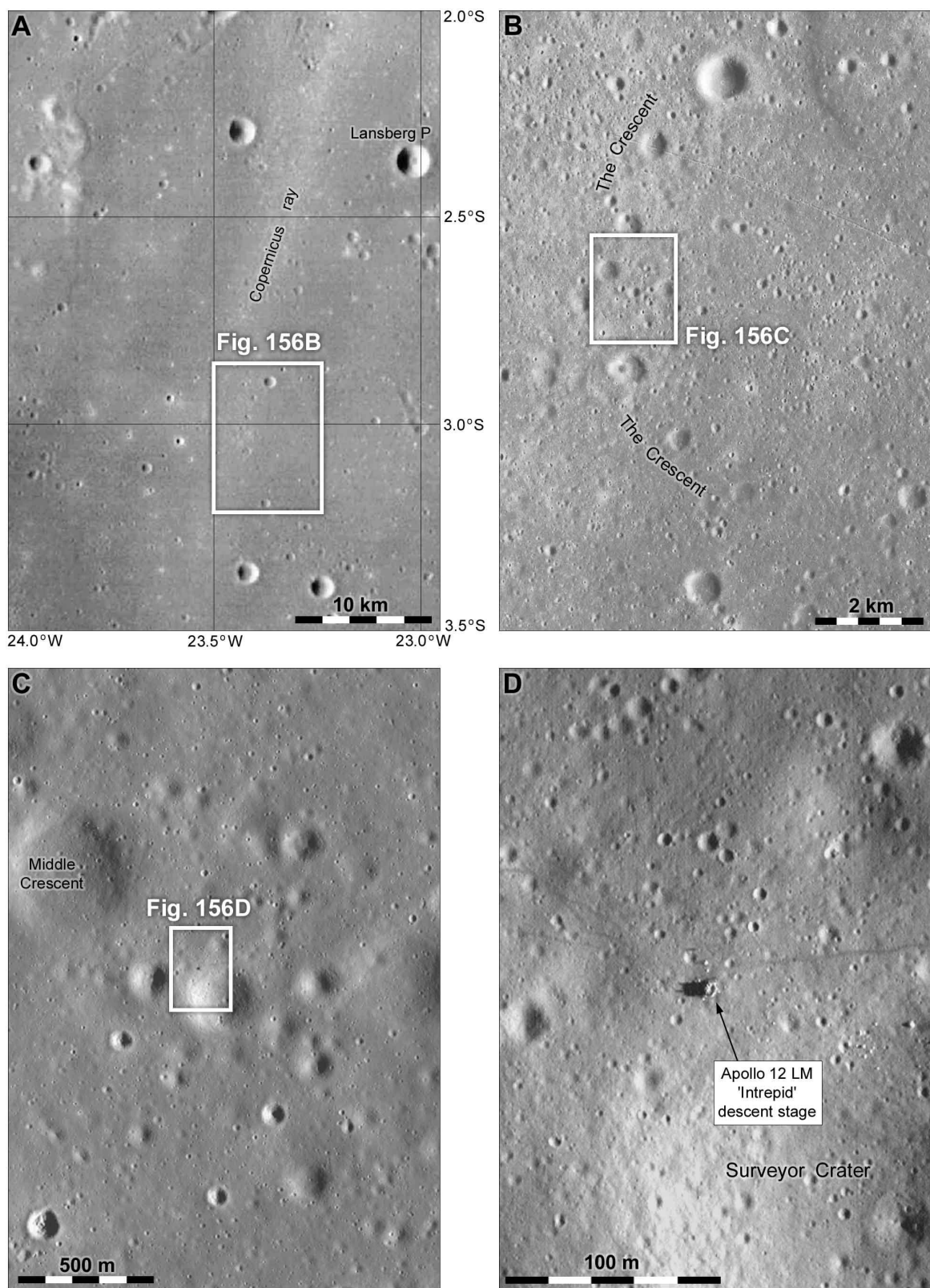


Figure 156. The Apollo 12 landing site. A: LROC WAC mosaic. B: Lunar Orbiter 3 image III-155M. C, D: LROC image M177785917. Compare with Figure 75 for Surveyor 3.

Figure 152A shows the Apollo 11 landing site, the Apollo 12 prime site (ALS-7) and the backup site (ALS-5). Prior to Apollo 11 Newell Trask had identified small fresh craters in landing sites 2, 3 and 5 as potential pinpoint landing targets (Table 47, Figure 139). Only site 5 was a suitable backup target for Apollo 12, and Trask had found nine fresh craters with blocky walls and ejecta in this ellipse. One of them offered two small fresh crater targets and a distinctive pattern of larger craters around it to guide the crew during landing, so it was chosen as the backup target. The ellipse is shown in Figure 152B and the chosen landing point is in more detail in Figure 152C. The ‘four crater cross’ would serve as a navigation landmark during descent. The crew would visit one or both of the indicated fresh craters, which have internal benches thought to indicate exposed bedrock (Wilhelms, 1993; El-Baz, 1969).

The Apollo 12 landing ellipse is shown in Figure 154A. The accuracy with which Apollo 12 could be guided to its target was still uncertain, given the experience with Apollo 11, so a standard size ellipse (14 by 5 km) and a smaller (5 by 3 km) ellipse were both considered. The nominal landing point (the landing site if everything went according to plan) was at the centre of the ellipse (above). The Flight Analysis Branch of MSC’s Mission Planning and Analysis Division performed studies (MSC 1969b) of the effects of dispersion of the trajectory caused by navigation uncertainties and mascon-induced gravitational effects. One of their plots shows dispersed landing points caused by the largest expected effects, shown as white dots in Figure 154A. Errors were more likely along the east-to-west orbit track than to the side. Coordinates given for these points (not matching the grid on this map because they were based on an updated coordinate system) are listed in Table 53.

Figure 154A also shows informal names for two navigation landmarks in the region, the Crescent, a curving chain of 400 to 800 m diameter craters, and the Three Sisters, a row of 250 to 400 m craters at the centre of the crescent. The middle crater of both the Crescent and the Three Sisters became known later as ‘Middle Crescent’ crater and was visited by the Apollo 12 astronauts (MSC 1969b).

A map carried on the mission and later signed and sold by Gordon included an oblique view of the landing area overlain with a triple landing ellipse. When matched with terrain features in Figure 154A the ellipses project into circles close to the easternmost dispersed landing point. No other representation of this ellipse has been seen by the author.

Apollo 11’s EVA could not be planned in advance because the landing point would probably be beyond walking range of the nominal target. Apollo 12’s expected ‘pinpoint’ landing allowed detailed preplanning for the first time, but several options were considered for different landing locations. These pre-mission plans are shown in Figure 155A. The original landing target used for navigation during descent was to be 300 m east and 150 m north of Surveyor 3, but this was brought nearer to Surveyor 3 as training proceeded (NASA graphic M-932-69-12, dated 29 October 1969). One or the other of these sites were shown in contemporary news reports and referred to as “Pete’s (or Conrad’s) Parking Lot”. The Commander could try to land closer to Surveyor 3 if sufficient fuel remained, but planners knew this first attempt at a ‘pinpoint’ landing might be somewhat off target. Plans were drawn up just before launch for possible landings at four sites in the vicinity, each with two EVAs laid out to visit and sample interesting locations (Figure 155A). These are not the same as the dispersed landing points in Figure 154A, which were worst-case scenarios. The first EVA would include ALSEP deployment, so it covered a shorter distance. Possible extensions to reach Surveyor 3 are shown for three EVAs (dashed lines). LM 1 was the closest to the target site.

Table 53. Dispersed Landing Points for Apollo 12

Landing Point	latitude	longitude
Nominal point	2.9822° S	23.39194° W
West of nominal point	2.965° S	23.473° W
East of nominal point	3.029° S	23.176° W
North of nominal point	2.962° S	23.389° W
South of nominal point	3.002° S	23.395° W

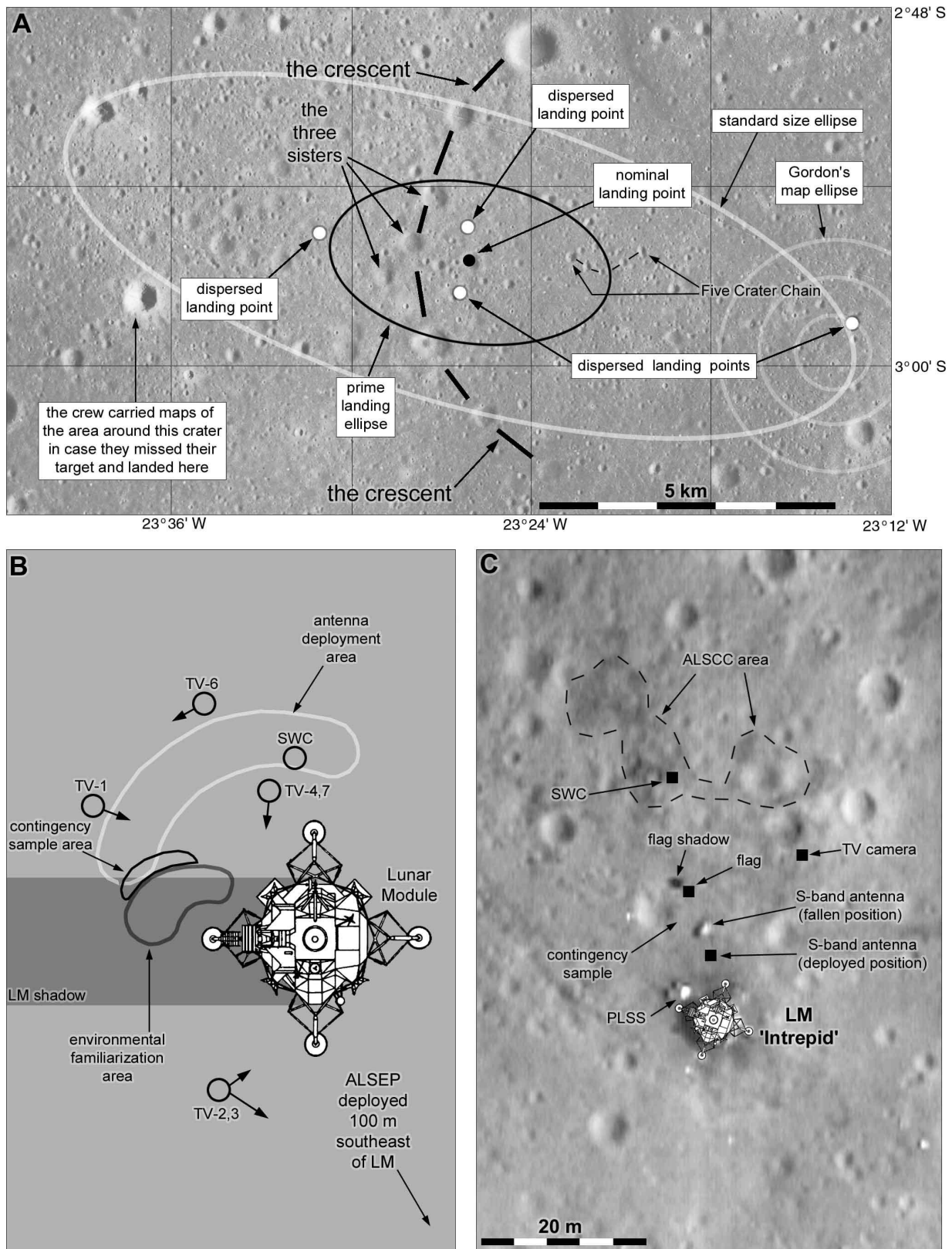


Figure 157: Apollo 12 landing site. A: landing ellipses, dispersed landing points and feature names. B: Planned activities near the LM from the Apollo 12 Press Kit. C: LM area in LROC image M175428601R.

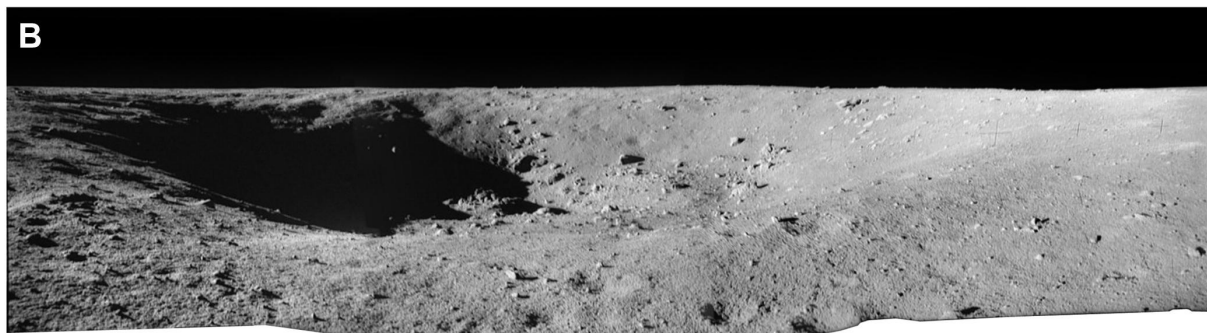
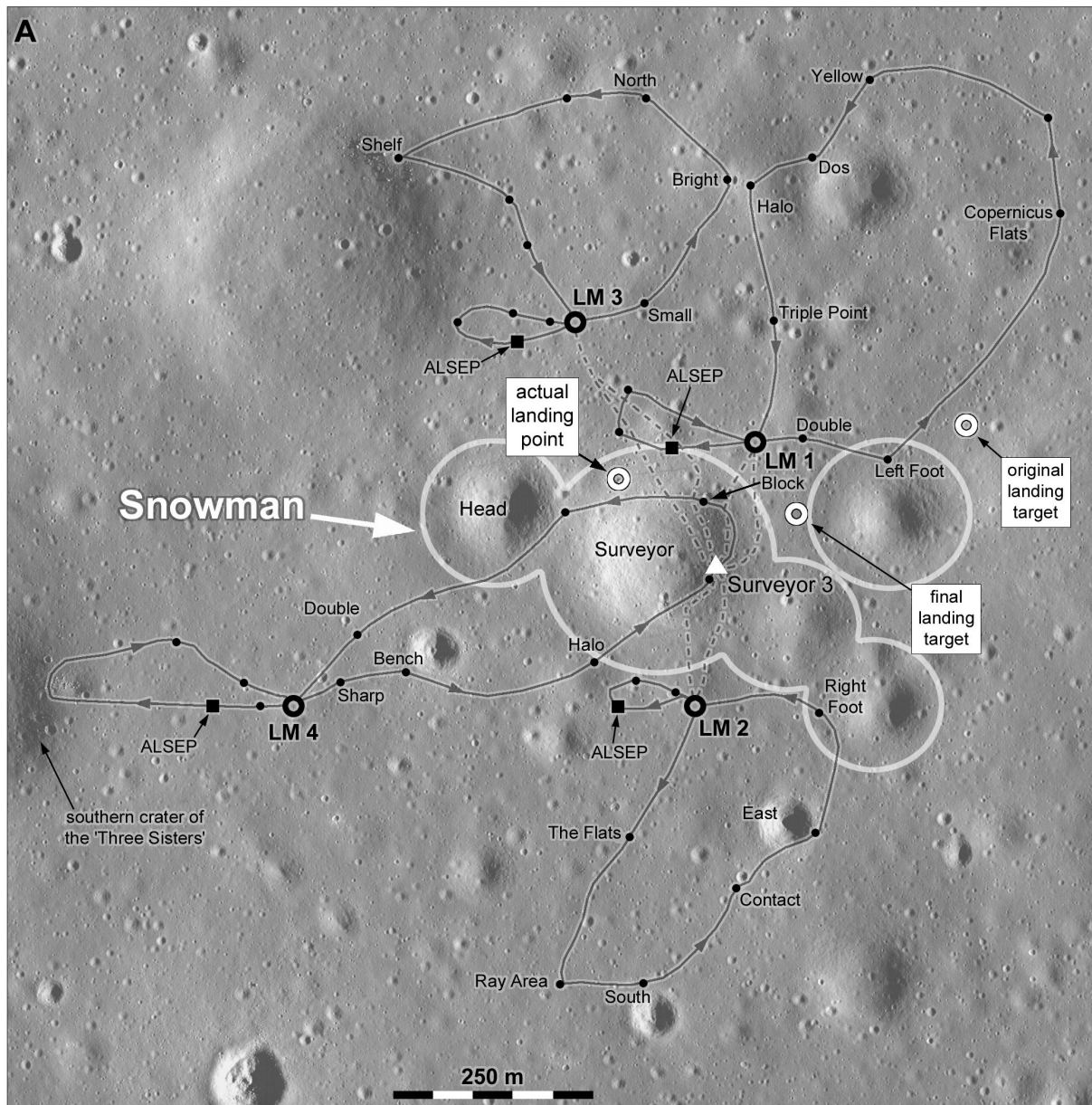


Figure 158. Apollo 12 landing site. A: targets and pre-mission EVA planning for four possible landing points. B: Bench crater, seen on EVA 2.

In Figure 154A, each of the four LM locations is shown as a black circle, and the ALSEP deployment area as a black square about 100 m west of the LM. Preplanned sampling sites are small circles on the EVA routes. Informal placenames are indicated. The name Shelf was sometimes used for the large crater at top left rather than the small local feature on its rim as shown here, and it was also called 'thousand-foot crater' from its diameter, but after the mission the large crater was renamed Middle Crescent. The 'crescent' was the string of 400 to 800 m diameter craters strung out north to south across the approach trajectory (Figure 157A).

Operations planned near the landed Lunar Module are shown in Figure 157B. As each astronaut stepped off the LM he would take a few minutes to familiarize himself with balance and walking in the lunar environment. The contingency sample would be collected nearby. The TV camera, initially mounted on the side of the LM to observe the crew's first steps, would be moved on its stand to the position labelled TV-1 for a panorama of the surroundings and then to monitor equipment unloading. The plan then called for the large S-band antenna and solar wind collector (SWC) to be erected as shown in Figure 157B. The camera would be moved to TV-2 to view ALSEP unloading and then reoriented (TV-3) to view ALSEP deployment. The deployment area here is to the southeast, not the west as in Figure 159A. At the end of EVA 1 the camera would be placed at TV-4 to view the return to the LM. During EVA 2 the camera would be placed at TV-6 (number 5 was not used) to view the long geology traverse, and then moved to TV-7 for the final operations, crew ingress and jettison of equipment. This plan is from the Apollo 12 Press Kit, 5 November 1969, and the TV directions are necessarily schematic.

Figure 154C shows the immediate landing area with the equipment deployed near the LM. The solar wind collector was exposed for 18.7 hours and then retrieved to return solar wind samples to Earth. The broken TV camera was also returned to Earth. The LM is shown at the correct scale and other features are shown schematically, but their locations are correct. The contingency sample was collected from the rim of a small crater immediately after landing, and a core tube sample was collected near the TV camera at the end of EVA 1.

An informal name widely used for Apollo 12 was Snowman, a group of craters including Surveyor and Head. The Snowman is outlined in white in Figure 158A. The easily recognizable Snowman was a navigation landmark for the LM crew during their descent. Another landmark on the approach was the Five Crater Chain, a curving string of craters resembling a reversed letter J (Figure 157A). Bench crater, shown on Figure 158A, was visited by the crew and is shown in a panoramic view in Figure 158B.

The pre-mission plans had to be modified when Intrepid landed on the north rim of Surveyor Crater. The actual landing occurred about 200 m west of LM 1, and the long second EVA was redesigned based on part of the LM 4 plan. The initial landing target and actual landing point are shown as white circles in Figure 155A.

After landing the astronauts spent some time checking the condition of the LM and preparing for a sudden departure if required, but found time to look out of the windows and describe the landscape. The first panoramic view from the windows (Figure 163A) was made 90 minutes after landing. They could tell fairly accurately where they were from their observations during landing and from the windows, since Bench and Head craters were clearly visible. Gordon, passing overhead 4 hours after the landing, was able to see the LM and its shadow as well as Surveyor 3, while Conrad and Bean were preparing for the first EVA.

EVA 1 began at 11.44 UT on 19 November, a little over 4.5 hours after landing. Conrad left the cabin first, pulling a cord to release the cover of the MESA (Modularized Equipment Stowage Assembly, where equipment and supplies were stored for access on the surface) and to deploy the TV camera. Bean photographed him as he climbed out. Conrad jumped down to the footpad and stepped off it, and at once could see Surveyor 3 sitting on the still shaded wall of Surveyor Crater, its mast and solar panel in sunlight while its footpads were still in shadow. He practised moving on the surface and then collected the contingency sample (Figure 154C) from the rim of a small crater just northwest of the LM. Moving to the MESA, he opened a thermal blanket and put the sample and some items needed to resupply the PLSS backpacks between EVAs in a bag which he then pulled up into the cabin on a strap (Lunar Equipment Conveyor, LEC). Bean stowed them and placed two cameras in the bag to send down to the surface. The astronauts could not pass through the small hatch with their chest-mounted cameras in place.

Conrad took a camera and began photographing the sample area and surroundings. Bean started an automated camera in the LM window and then climbed out and down the ladder. Conrad then deployed the large S-band antenna to ensure good communications with Earth. A cover from the antenna was dropped onto the north footpad

of the LM and used later to cover a sample box. Conrad had removed the TV camera from its initial position on the MESA and set it down on its side, so it had been transmitting a steeply tilted image, but after helping with the antenna deployment Bean fixed the camera to its tripod and carried it out to its first deployment position southwest of the LM. He noticed that this would cause the camera to look towards the Sun as it documented their activities at the MESA, so he moved it northeast of the LM. Unfortunately, at the first deployment position it had been accidentally pointed directly at the Sun, damaging its vidicon sensor. After this experience, Apollo 13 carried a backup TV camera, and later cameras were improved so they would not be susceptible to the same problem.

Conrad finished deploying the S-band antenna and connecting its cable to the LM, assisted by Bean while the ground support team considered the camera problem. The big antenna was not used now, but was tested at the end of the EVA and activated for the second excursion. Bean then deployed the SWC about 20 m northwest of the LM, but decided it was not far enough away and moved out another 10 m (Figure 154C). Then the flag was deployed nearby. The lower part of the flagpole was hammered into the surface to fix it more securely than the Apollo 11 flag. Early plans suggested that only Apollo 11 would carry a flag, but eventually all missions set one up. The flag was suspended from a cross-bar, but on Apollo 12 the crossbar would not deploy properly and the flag remained only partially unfurled. Bean returned to the camera but could not fix it, even by hitting it with a hammer, so no further TV transmissions from the surface were possible.

Conrad took three panoramic photo sequences to document the landing site, from positions west, northeast and southeast of the lander (Figure 159C), as Bean inspected the state of the LM and its landing gear. Next the two men removed the ALSEP components from their storage area in two packages, the plutonium fuel rod was placed in the Radioisotope Thermoelectric Generator, and the two packages were attached to a bar for transport to the deployment site. Bean lifted the bar and carried the two packages, one on each side of him, about 120 m to the northwest, to a level site selected by Conrad who had walked on ahead. Conrad was intrigued by a prominent regolith mound about 150 cm high, conical with a flat top, and imaged it as Bean approached with the ALSEP. Bean then noticed a similar but smaller mound to the north (Figure 159A).

The ALSEP instruments were set out between small craters (Figure 159) and were connected by cables to a Central Station which collected and transmitted data to Earth. Electrical power was provided by a small nuclear generator (Radioisotope Thermoelectric Generator, RTG). The Magnetometer detected a weak local field and the effects of the Moon's passage through Earth's magnetospheric tail. The Solar Wind Spectrometer (SWS) characterized the solar wind and Earth's magnetospheric tail. The Suprathermal Ion Detector Experiment (SIDE) examined the lunar ionosphere, including any ionized products of gases emitted from the Moon itself or the LM. The Cold Cathode Ion Gauge (CCIG) was designed to detect atmospheric gases from the same sources. It failed after 14 hours of operation. The Apollo 12 ALSEP operated until 30 September 1977 when all the ALSEPs were turned off, though by then many experiments were no longer working.

Conrad set out the SIDE and prepared to connect its cable to the Central Station, which Bean had now positioned correctly. Bean deployed the seismometer base, trying to tamp down the regolith where he would place it to provide better coupling to the surface. Then the RTG was put in place, and its cable and the SIDE cable were connected to the Central Station. The SWS was put in place by Conrad, who then set out the magnetometer about 15 m southeast of the station while Bean put the seismometer on its base. The Central Station was finally deployed after the other instruments were ready, and Bean finished deploying the magnetometer. Then he carried SIDE out to its final position 20 m southwest of the station and set up the CCIG beside it. ALSEP deployment was complicated and was slowed by unexpected problems with bolts and cables, but everything was eventually completed (Figure 159B) and documented with photographs. Deployment concluded as Conrad turned the ALSEP on and Bean aligned the Central Station antenna, and Houston reported at once that the first data were being received on Earth.

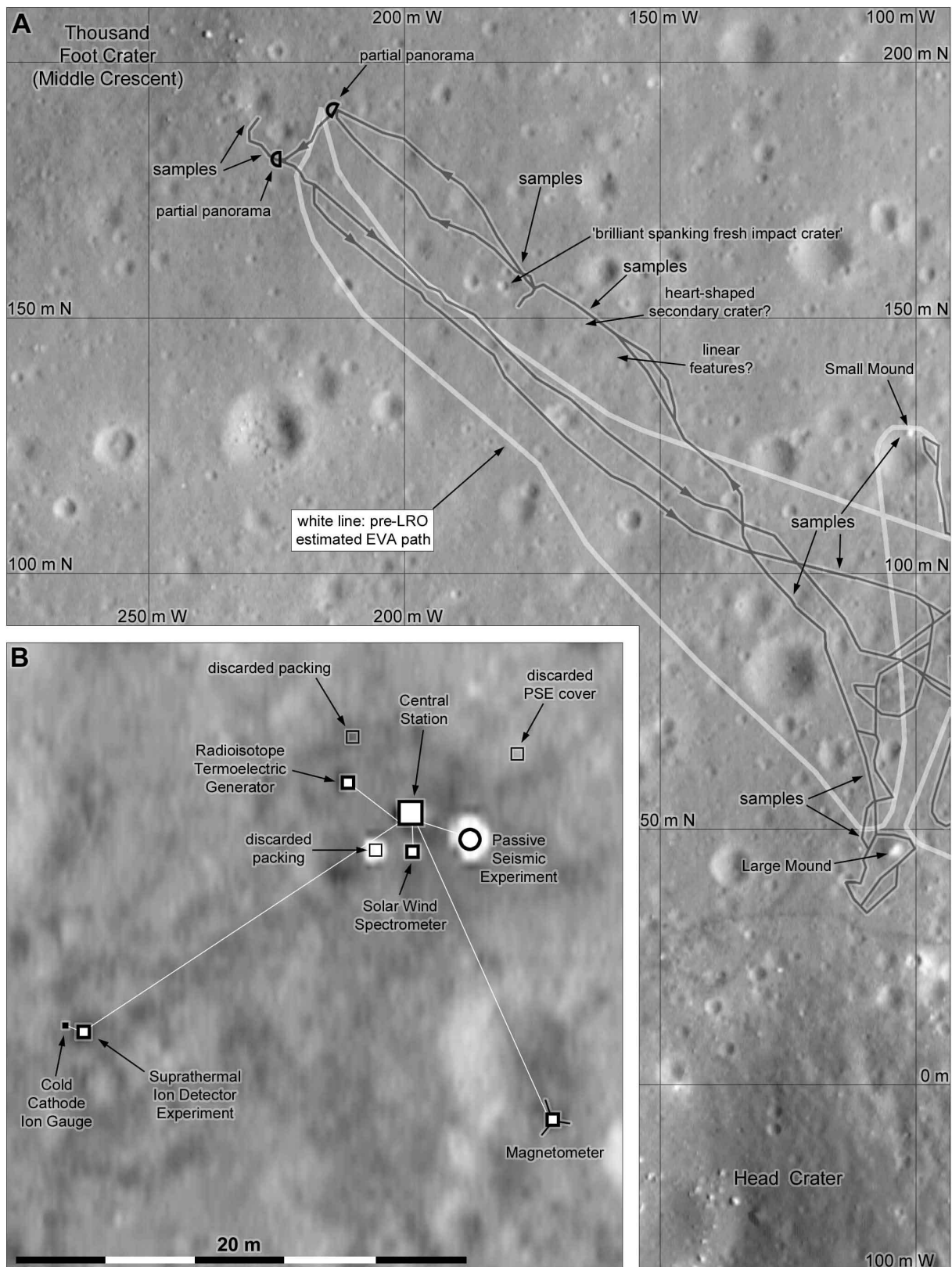
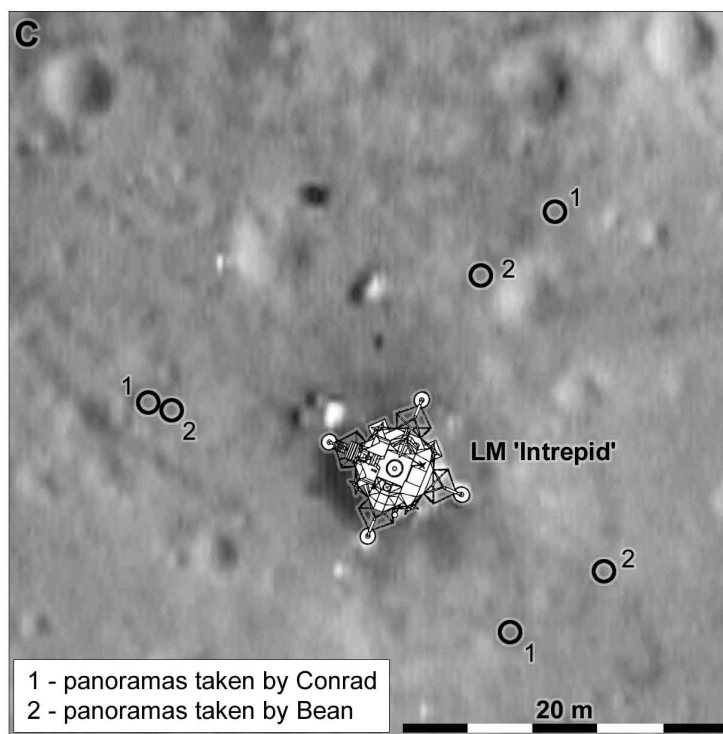
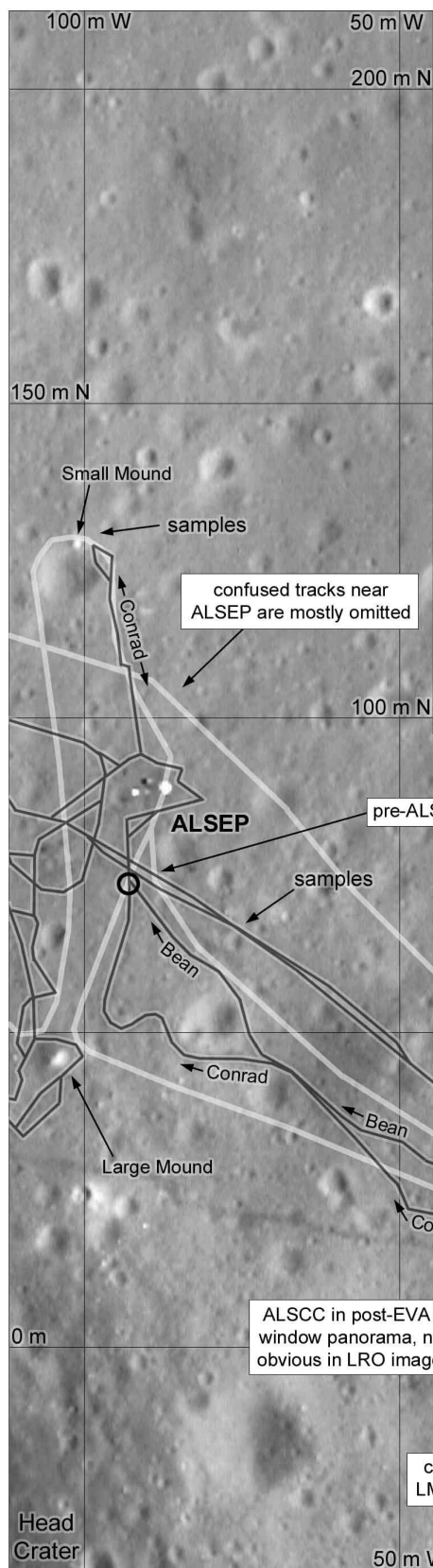


Figure 159 (both pages). Apollo 12 EVA 1. A (both pages): EVA 1 map. B: ALSEP area. C: LM area.



Three hours into the EVA, with the equipment all set up, the crew set about collecting a larger set of lunar samples, 'selected samples', the equivalent of Apollo 11's bulk sample. Conrad approached the small mound north of the ALSEP and photographed it. Back at the ALSEP, the astronauts found and collected a black glass-coated rock. Conrad walked to the large mound to photograph it, and then both astronauts collected rocks on the rim of Head Crater. They then walked quickly another 170 m northwest to the rim of Middle Crescent Crater, referred to at the time as 'the thousand-foot crater'. Bean described north-south trending linear patterns in the regolith near here, either optical illusions caused by the low sun or perhaps real features produced by sprays of ejecta from one of the many small craters nearby. He also noted a very young-looking heart-shaped secondary crater, and near Middle Crescent Conrad noted a 'brilliant spanking-fresh impact crater' from which they collected samples.

Very little time remained in the EVA, so at Middle Crescent Conrad took two partial panoramas across the shadowed crater interior (Figure 163D) while Bean noted rocks he would like to sample if time permitted, including what he thought looked like a bedrock outcrop 50 m further into the crater. They were able to collect some rocks before Houston insisted they return to the LM. They stopped for more rock samples during their run back to the ALSEP area, and a distinctive green (olivine-rich) rock and a glass fragment a little later. Back at the LM, Bean retook the three panoramas that Conrad had taken earlier because Conrad was concerned that the first set had been spoiled by incorrect focus settings. Next, as Conrad worked with a sample box at the LM, Bean hammered a core tube into the surface near the TV camera to study layering in the regolith. Its core sample was 19 cm long. Bean tried changing settings on the TV camera, instructed from the ground, but could not repair it. Before the end of the EVA it was carried back to the LM and placed in its shadow. The rock sample box was placed on a footpad in sunlight with part of the S-band antenna cover over it to keep its temperature within acceptable limits. The Apollo 11 sample box had been hard to close properly because the seals were too cold. Conrad put the ALSCC in the sun as well. It had not been used yet and would not be until the end of EVA 2. Finally the two astronauts dusted each other off with their gloves and Bean climbed the ladder.

Bean entered the cabin first and switched LM communications to use the S-band antenna before Conrad climbed the ladder. He threw out a jettison bag containing materials they no longer needed and used the lanyard to pull a bag containing the two cameras up into the cabin. Then a sample box was pulled into the LM and then Conrad entered the cramped LM cabin, the hatch was closed and the cabin repressurized. EVA 1 had lasted 3 hours 56 minutes. The PLSS supplies were replenished from LM systems, and back in orbit, Richard Gordon adjusted the CM orbit plane to be ready for the LM's return to orbit. The crew took a panorama from the windows to document EVA activities before all the camera film magazines were replaced. The crew discussed the first EVA and plans for the second excursion with Houston, and Conrad noted that his boots were wet inside. They ate some food and then slept for a few hours in hammocks rigged across the cramped cabin.

The first EVA is depicted in Figure 159, with panorama and approximate sampling locations noted. Panoramas were designed to provide exact locations for equipment or activities and to show the nature (roughness, rock distribution etc.) of each locality. A typical panorama consists of between 12 and 20 images taken as the astronaut turned around in place. The total distance walked was about 800 m. Figure 159 also shows the pre-LRO estimate of the path followed by the astronauts, which is often erroneous. Small circles in Figure 159 are the locations of panoramic photographs, and semicircles indicate partial panoramas, as at Middle Crescent crater.

As soon as the approximate landing point became clear, mission planners in Houston sketched out a possible route for the second EVA (Figure 160A, based on an image from the Apollo Lunar Surface Journal website). This version of the plan included stops at several craters, a descent to the bottom of Surveyor Crater and a visit to Surveyor 3 (point 5). It is a modification of one of the routes shown in Figure 158A, the longer traverse from LM-4. The astronauts descended into Surveyor Crater from the eastern wall rather than from the west or south (Figure 160B).

The astronauts woke after a rest period in which the astronauts found themselves unable to sleep well. Scientists in Houston had noted that the CCIG was not transmitting as expected but the astronauts could not see it to verify it was in the proper orientation since it was deployed behind SIDE as viewed from the LM. Houston provided instructions for bringing the damaged TV camera back to Earth and for the redesigned second EVA, and the crew observed that the Solar Wind Collector, the Swiss experiment also set up by Apollo 11, seemed to have warped since its initial deployment as a flat sheet. This turned out to be simply an illusion or lighting effect. Houston relayed messages from the astronauts' families, and then the crew prepared their suits and PLSS 'backpacks' for the second EVA.

EVA 2 began at 03:55 UT on 20 November (still 19 November in the United States), 1 hour 40 minutes ahead of schedule and lasted 3 hours 49 minutes. The route and activities are illustrated in Figure 157B. After depressurizing the cabin and ensuring the suits were working properly, the astronauts jettisoned a bag of unwanted items and then Conrad climbed down from the LM. He loaded tools into a holder called the Hand Tool Carrier (HTC) while Bean prepared an equipment bag to be passed down to the surface. Bean left the cabin and joined Conrad, who noted that Surveyor 3 was now fully illuminated. They collected the damaged TV camera for return to Earth and pointed out a 9 cm rock just below the descent engine which had not been ejected by the rocket exhaust, though the regolith around it had been scoured. When the HTC was fully loaded Conrad walked to the ALSEP to check the orientation of the CCIG, which did not need to be changed. His approach was recorded by the seismometer. Next he collected a grapefruit-sized rock sample and rolled it or another rock down the slope into Head Crater. Houston reported some possible seismic signals from the rolling rock.

Meanwhile Bean was taking photographs of a contrast chart just north of the LM to compare visibility in and outside shadows, and looking at the SWC, which did not look twisted on close inspection. He then carried the HTC to the north rim of Head Crater, stopping to collect a glass-coated rock on the way and passing a small wide-rimmed crater. Conrad had moved a rock to take polarized light images of the regolith under it, and noted a green crystal in the rock. When Bean joined him, Conrad kicked another rock down into Head Crater, but it was too small to register on the seismometer. Then, checking a map of the EVA route (Figure 160A) which they had sketched in the cabin from Houston's instructions, they moved to the west near Triple Crater. Conrad's footprints here exposed light grey material below a darker surface layer, taken as a sign that Copernicus ray material might be present at the site, as had been hoped. They used a shovel to dig a 15 cm deep trench, exposing the light-toned layer, and sampled it. Before they moved on to Bench Crater they stopping briefly to photograph the largest of the Triple Craters and take a full panorama. From here the lower half of the LM was hidden by a high point on the rim of Head Crater.

Just southwest of Head Crater, on the way to Bench, the crew observed rounded rocks with fillets (debris banked against the rock) on all sides and collected some samples. Most samples collected on the 1500 m traverse were documented with stereoscopic and before and after photography. Bench Crater was surrounded by rocks and contained an interior ledge or bench which indicated it had penetrated the local bedrock under the regolith. This was the same type of feature Newell Trask had been looking for in his pinpoint landing targets (Figure 139). A rock found partially buried near Bench Crater had a strikingly iridescent coating, probably impact glass, and regolith disturbances again revealed lighter toned material beneath a darker surface. Houston asked if the astronauts could get down to the floor of Bench, but they felt its walls were too steep. Instead, the interior was documented with two partial panoramas (Figures 158B, 160B).

The astronauts briefly had difficulty locating Sharp Crater, and took a full panorama of the scene on their way to it. When they found the crater they noted that the light-toned material seen earlier under a darker layer was at the surface here and the crater had a distinct radial ejecta texture. Conrad took two partial panoramas of the crater and dug a 20 cm deep trench on the crater rim. They gathered regolith samples including some which were packed in special containers to prevent contamination by the atmosphere in the spacecraft and on Earth, and Bean took a core sample at the bottom of the trench. The regolith was very soft around Sharp, but noticeably firmer around Bench as they began the return journey from this most distant point on the traverse, about 400 m from the LM.

The astronauts were directed due east to Halo Crater, but found visibility poor if they walked directly towards the Sun. Glass beads were noted in the regolith throughout the EVA, but especially here, just after passing Bench Crater. The common occurrence of glass is a result of sudden melting and cooling of rocks and soil during impacts in the vicinity. They made their way back to the rim of Surveyor Crater, finding a firm regolith with a distinctive texture, and collected samples. Then they turned southeast to find Halo Crater, where they would take a photo panorama and a double core sample as well as other samples. Bean took the core sample just south of Halo Crater, using two core tubes to get as deep as possible. They had to be hammered into the firm regolith.

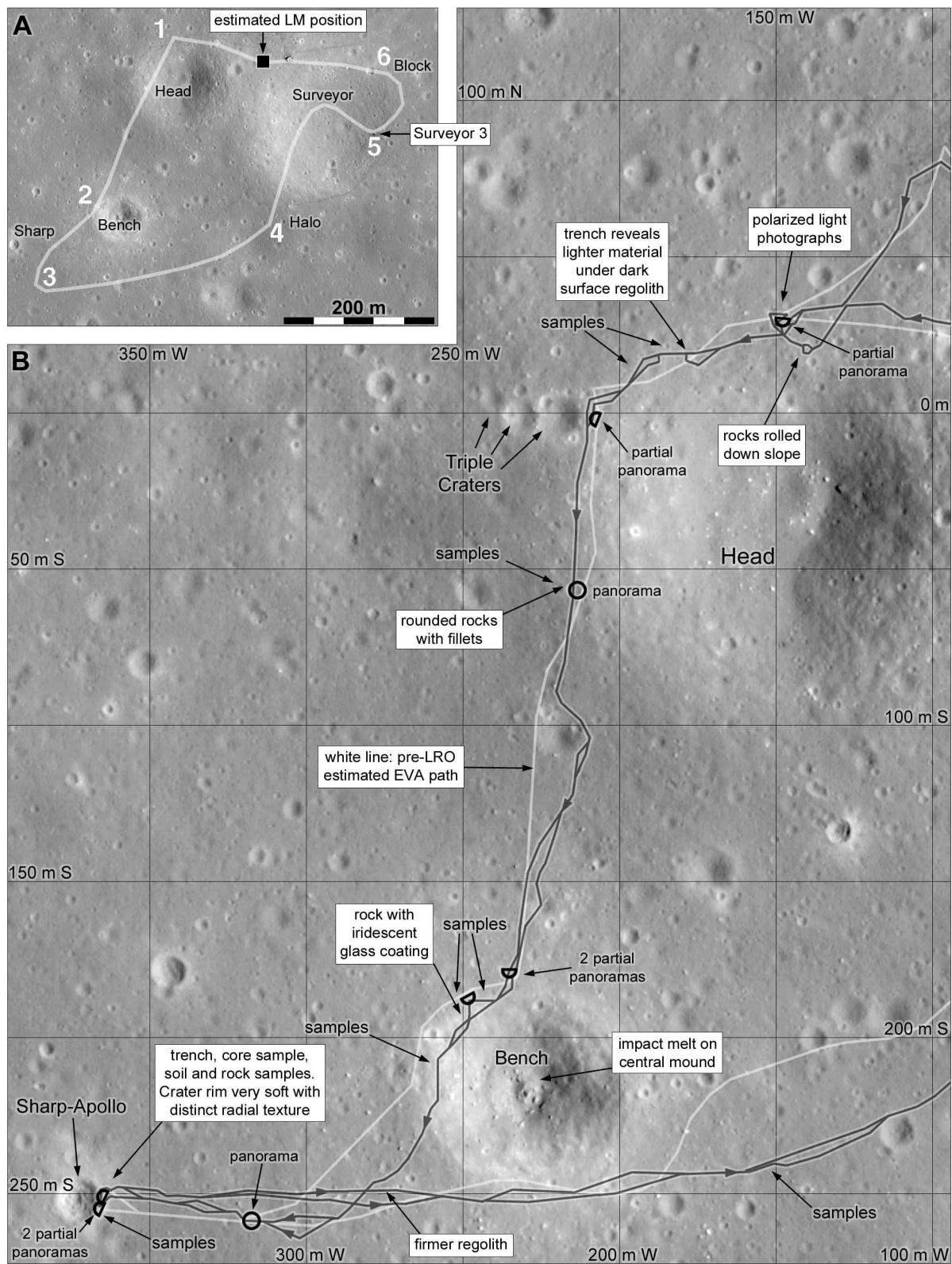
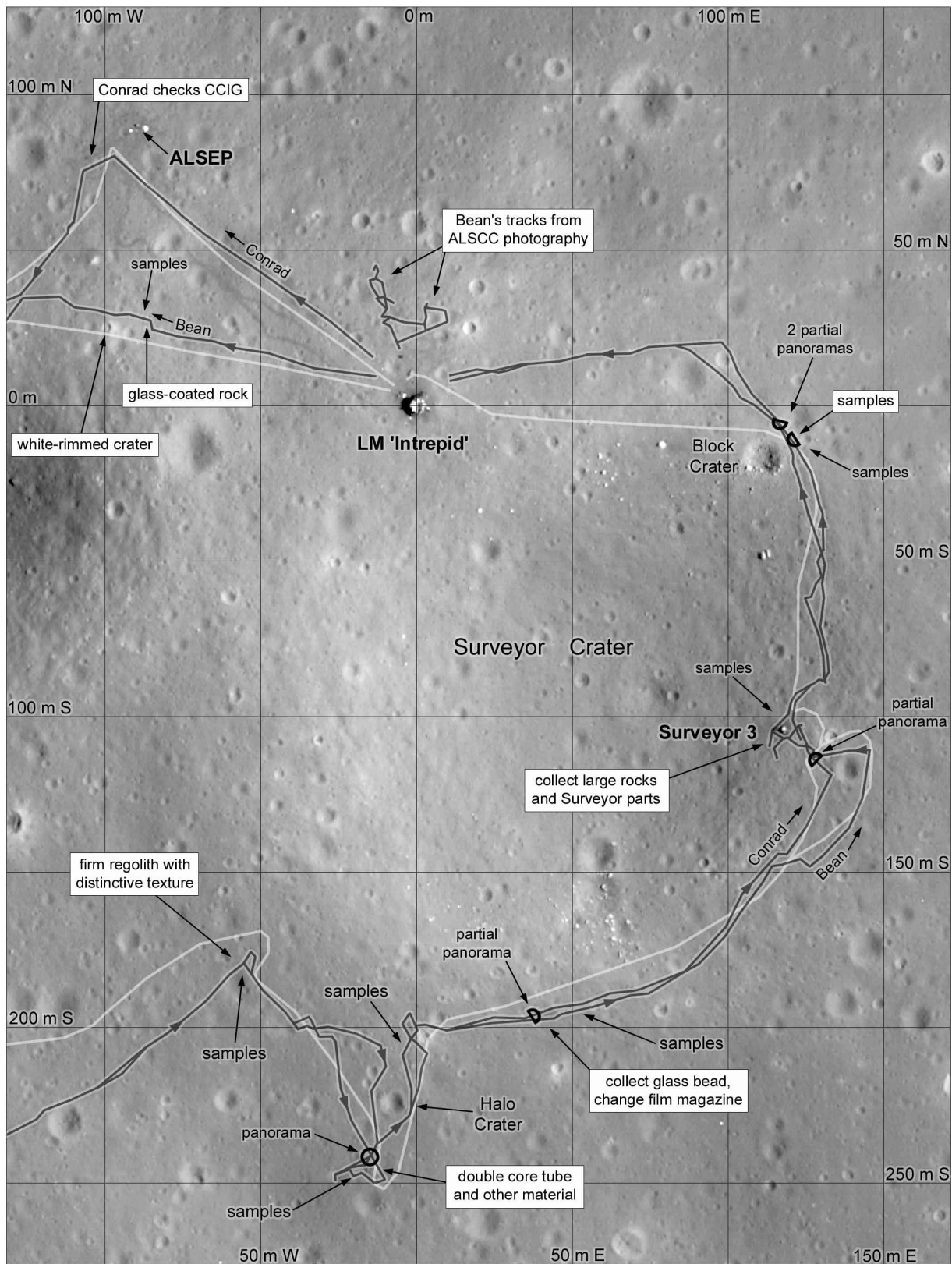


Figure 160 (across both pages). Apollo 12 EVA 2. A: plan drawn in Houston between EVAs. B (both pages): EVA 2 activities.



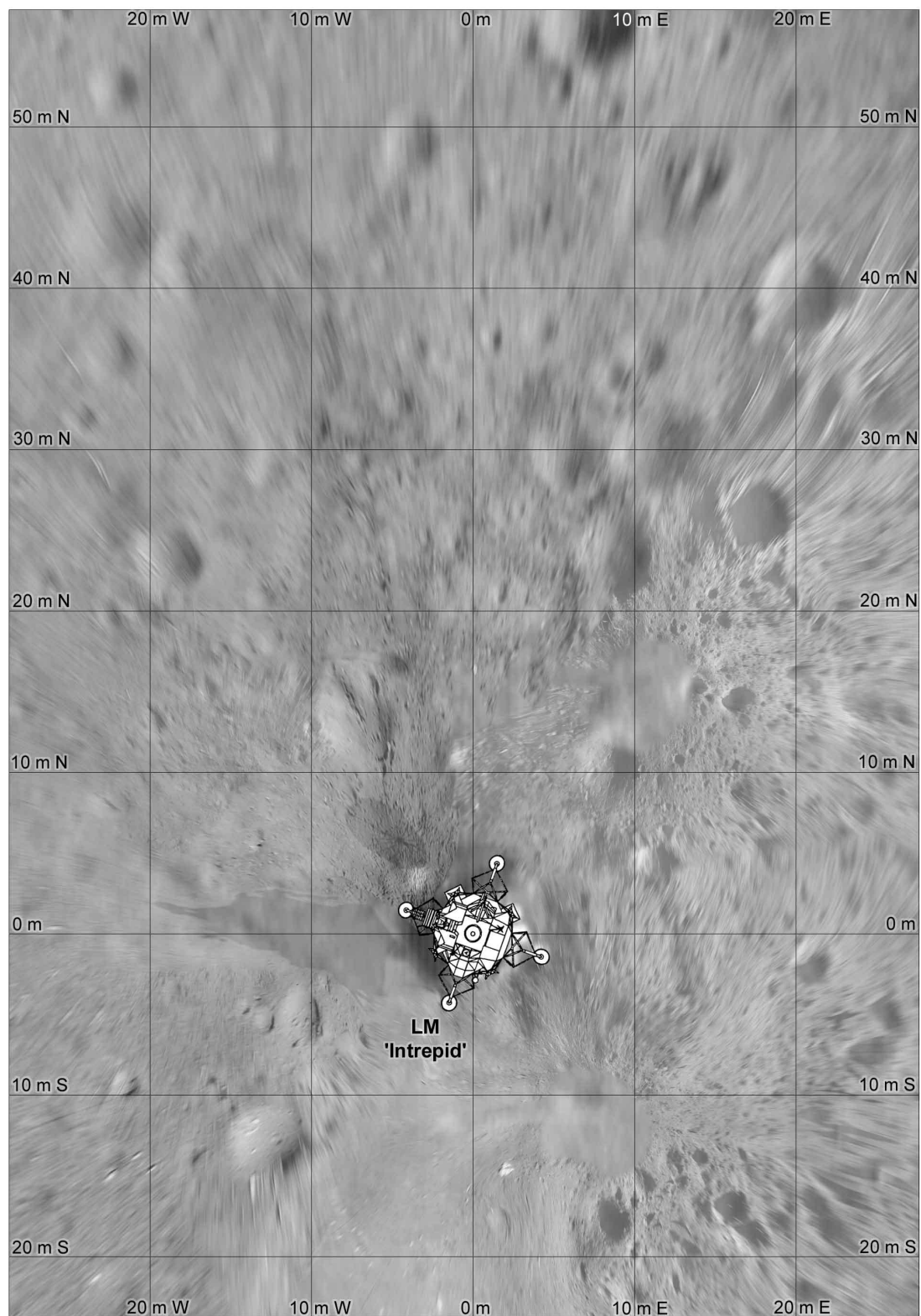


Figure 161. Apollo 12 Lunar Module area. This is a composite of merged LRO images and reprojected surface and window panoramas.

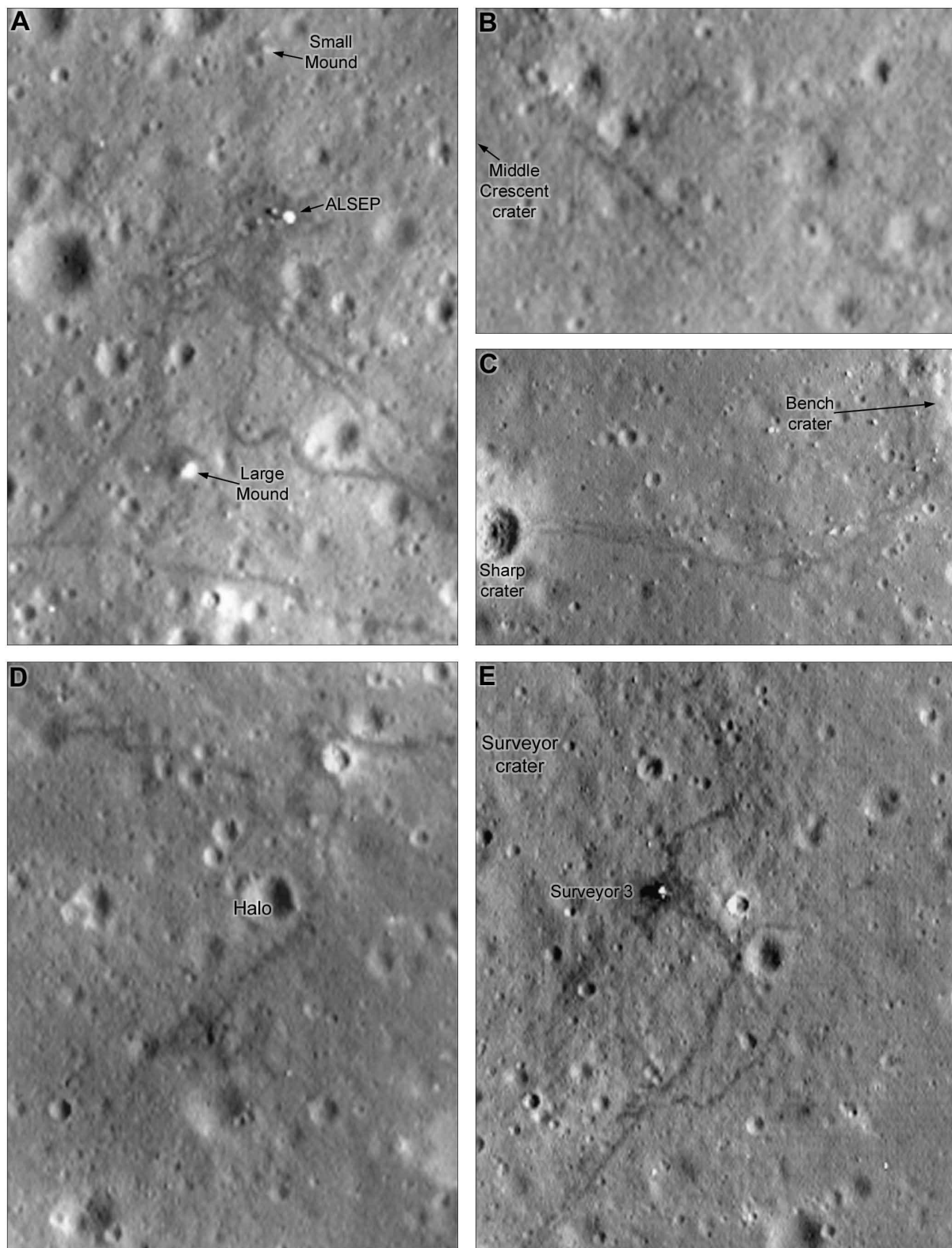
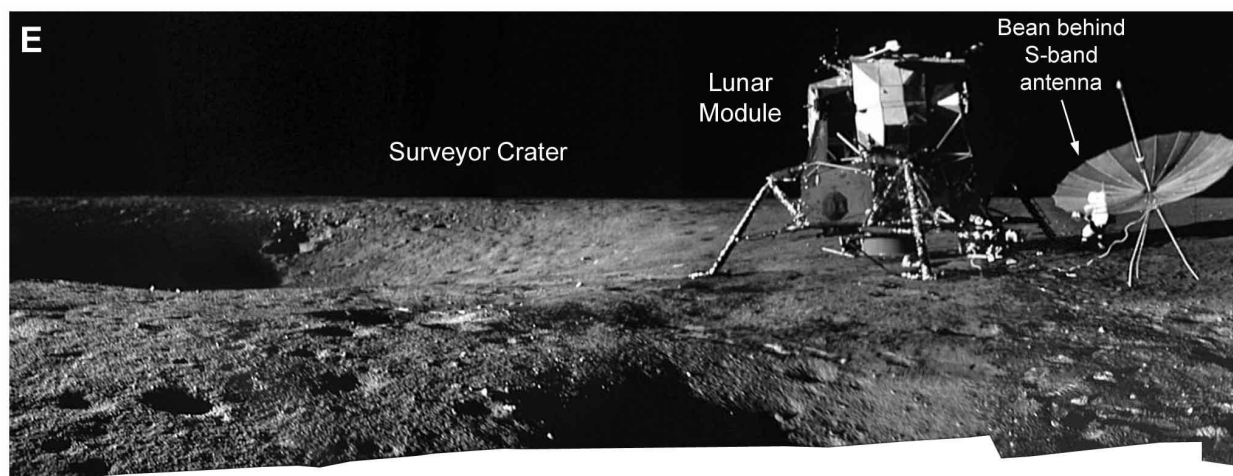
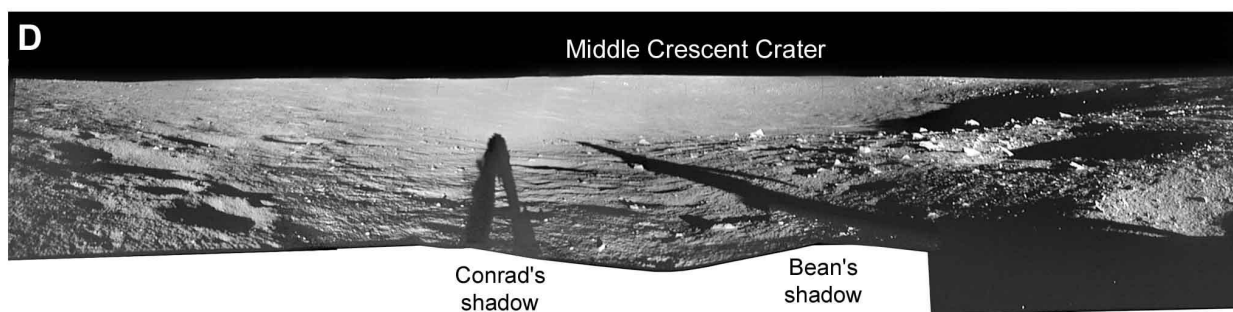
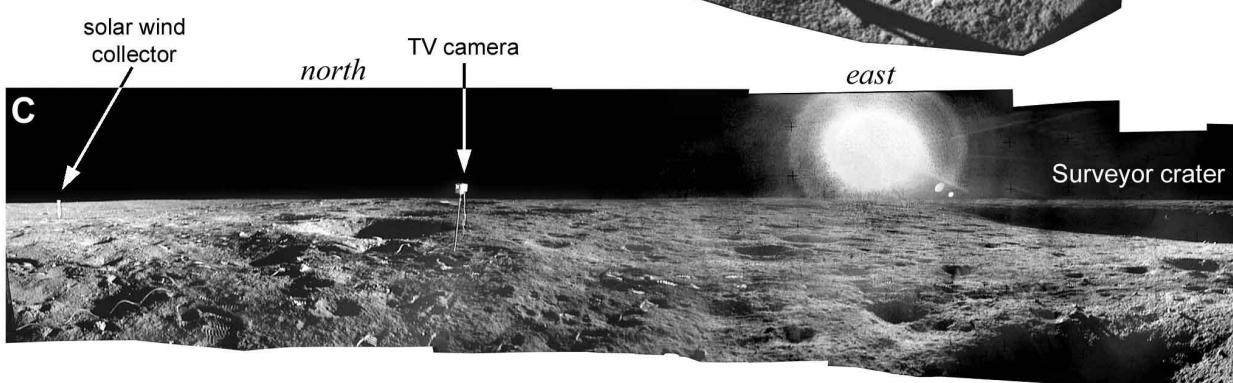
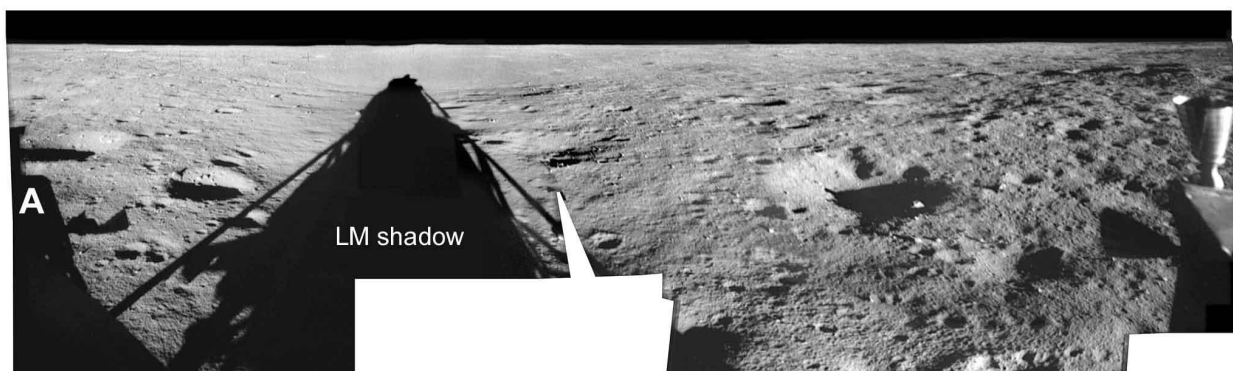


Figure 162. Sites on the Apollo 12 traverses. A: ALSEP area. B: Middle Crescent. C: Sharp crater. D: Halo crater. E: Surveyor 3 area.



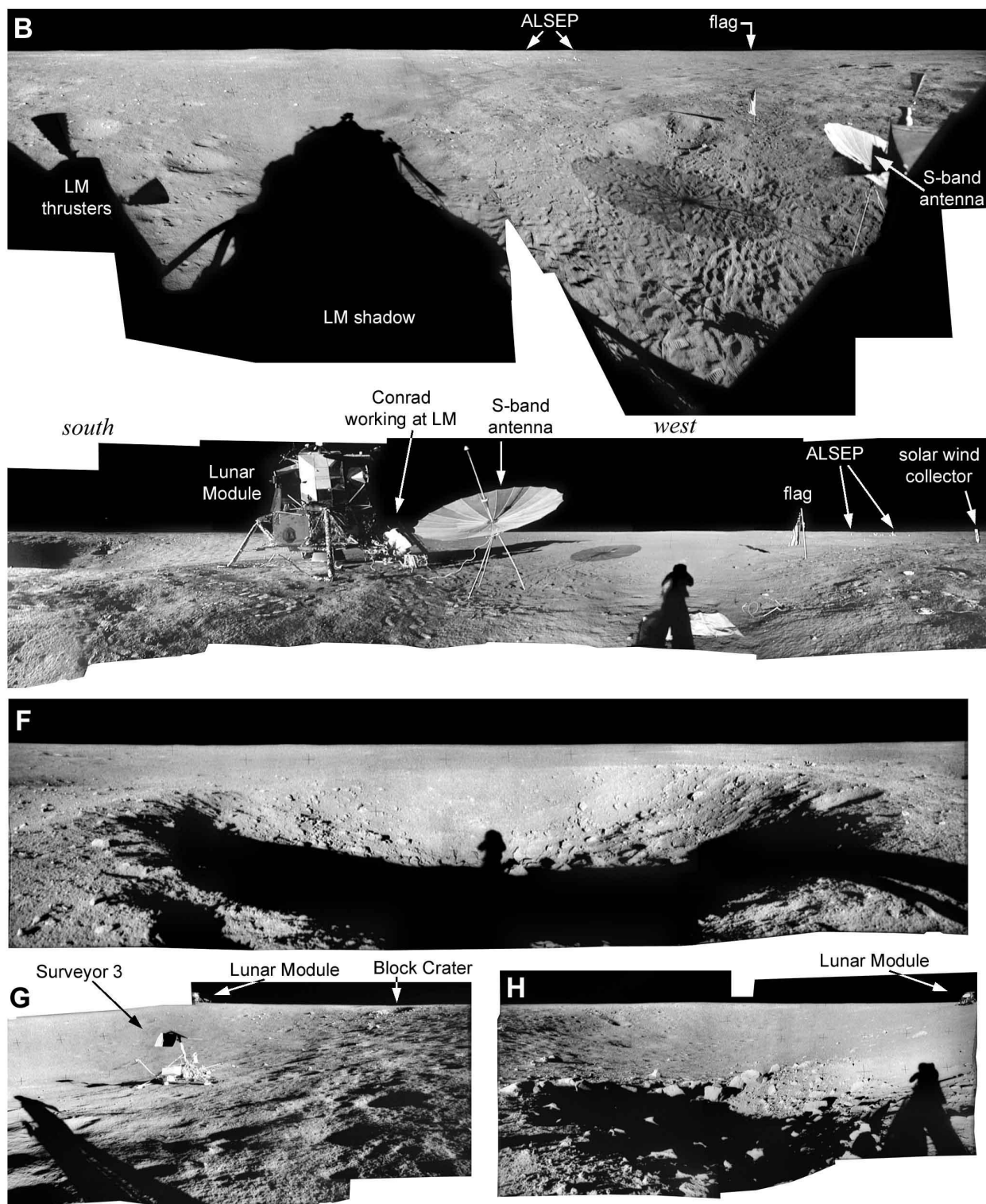


Figure 163 (across both pages). Apollo 12 panoramas. A: pre-EVA 1 window panorama. B: post-EVA 2 window panorama. C (across both pages): full panorama north of the LM. D: Middle Crescent Crater panorama. E: Surveyor Crater and the Lunar Module. F: Sharp Crater. G: Approaching Surveyor 3. H: Block Crater. See also Bench Crater, Figure 158B.

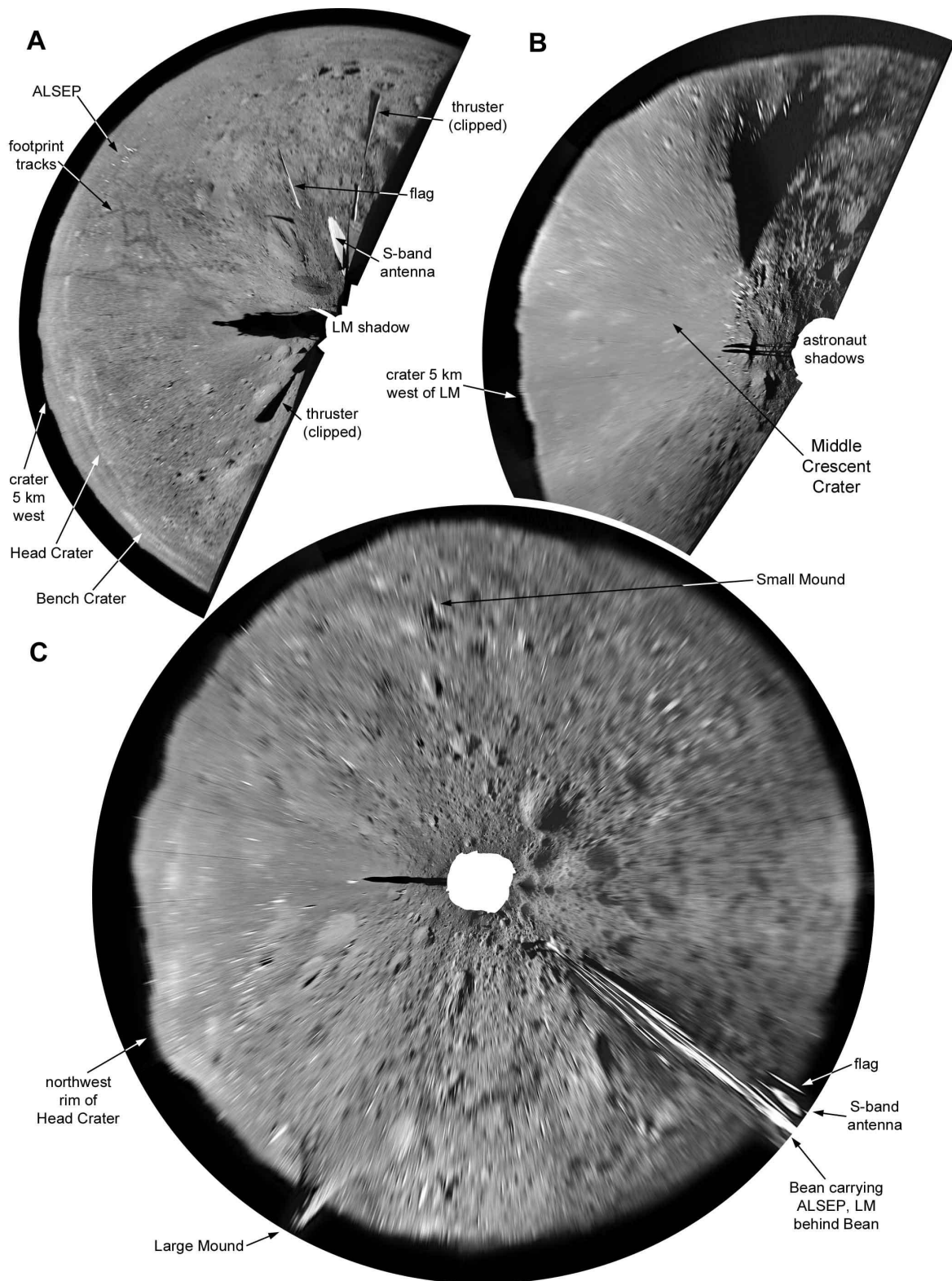
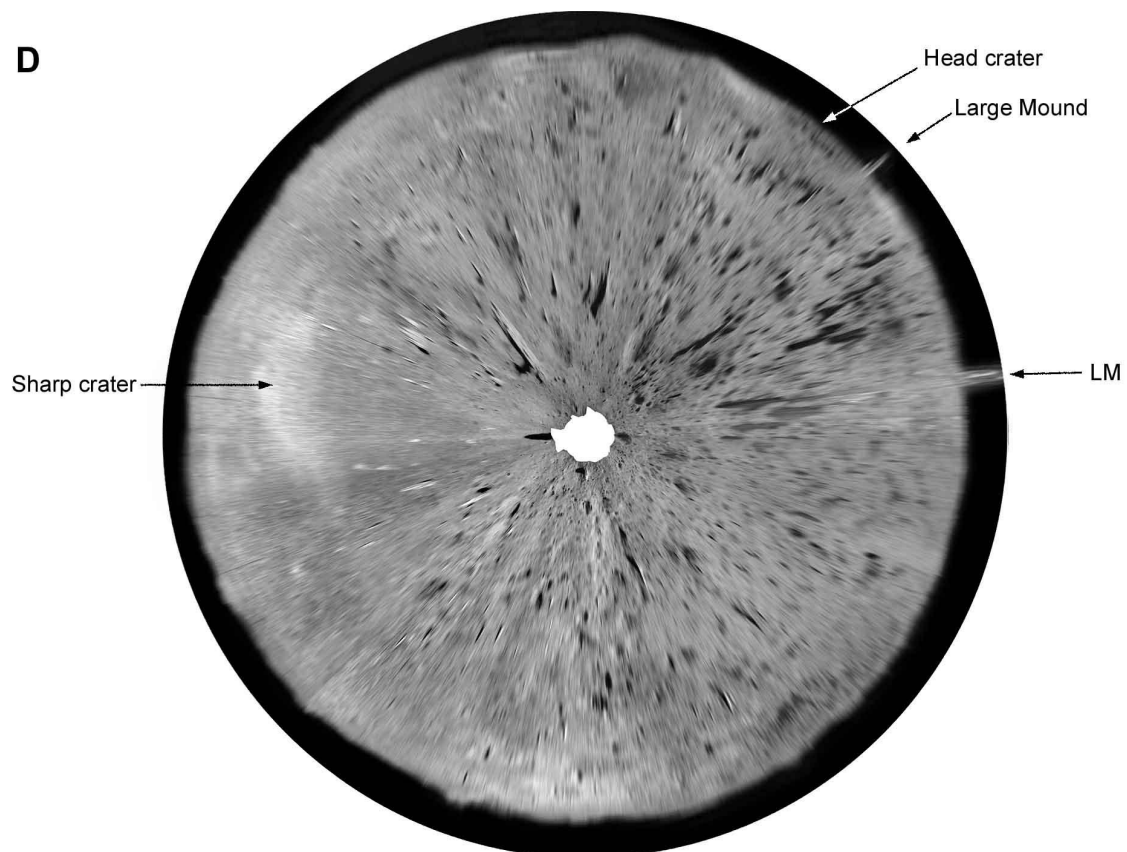
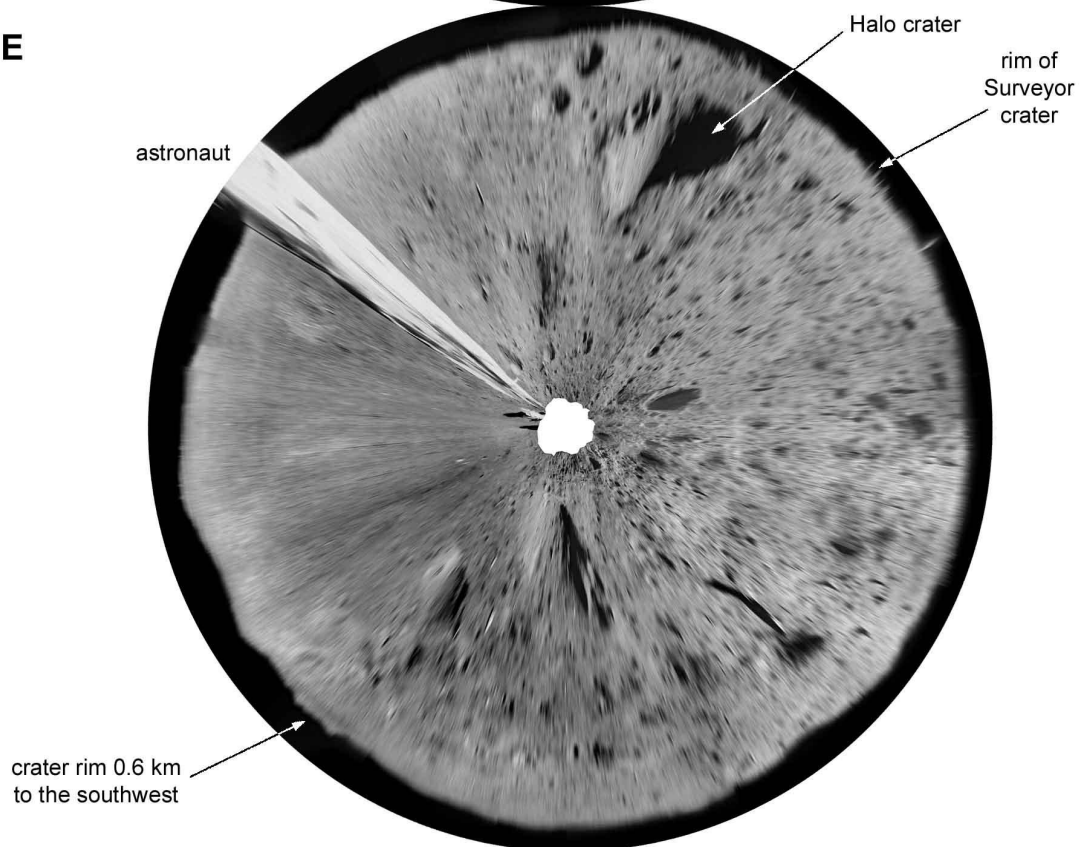


Figure 164 (both pages). Apollo 12 reprojected panoramas. A: post-EVA 2 window panorama. B: Middle Crescent Crater. C: ALSEP deployment area. The projection method exaggerates the height of distant features such as the Large Mound. D: panorama east of Sharp crater. E: panorama at Halo crater.

D



E



Meanwhile the cameras they carried were causing problems. The controls for advancing the film in both cameras came loose and only Conrad's could be tightened again. One sample collected here was apparently lost and remains on the Moon. Another sample which did come home was a glass-spattered shatter cone, a distinctive conical rock produced in an impact, probably from a large impact some distance away rather than one of the local small craters. As they walked back to the rim of Surveyor Crater just north of Halo they took some pictures showing the LM on the other side of the large crater, and changed the film magazine in the camera. They collected a glass bead and some rocks on the crater rim just above a prominent rocky crater on the southern wall of Surveyor crater.

The astronauts approached Surveyor 3, and when they were roughly 50 m south of it and high on the rim of the crater, Conrad began to descend the slope diagonally, stopping when he was almost above the old lander. Bean stayed high on the rim, walking until he was directly above Conrad and then descending. He did not observe the footpad impressions from Surveyor's earlier touchdowns, especially the first which Surveyor itself could not observe, though Conrad noticed the second bounce impressions while they were working on the Surveyor. The wall slope had been a concern to mission planners and the crew carried a tether which could have been used to help one astronaut pull the other up the slope if the surface was soft or unstable. Similarly the earlier plan to approach Surveyor from below (Figure 157A) had been scrapped, in case it shifted on the slope when disturbed, but in fact the crew had no difficulty working on the slope.

The astronauts photographed the Surveyor and its footpad imprints and trenches, looking for changes to the spacecraft and surface features. The once white spacecraft appeared to have turned brown in places because a small amount of dust had been thrown onto it by Intrepid during the landing. Several chips caused by micrometeorites were found on its returned parts (Cour-Palais *et al.*, 1970). After taking 'tourist' photos of each other beside the Surveyor, they started to remove some parts of the spacecraft, beginning with a section of cable and a metal tube. These were packaged in a sterile container to avoid contamination. Another tube proved too strong to cut off with their tools, so a substitute was chosen and retrieved. Several components including the TV camera and soil scoop were retrieved for study and can now be seen in the National Air and Space Museum in Washington, DC, at NASA Headquarters in Washington, D.C., at the Jet Propulsion Laboratory and elsewhere. Some *Streptococcus* bacteria were found in the camera, most likely as a result of contamination after the Apollo 12 flight (Billing, 2012) rather than from surviving on the Moon for 3 years as sometimes suggested.

Work at Surveyor concluded with the collection of a few samples including rocks seen in Surveyor 3 images. The astronauts were careful to avoid sharp edges or glass fragments and potentially corrosive chemicals from Surveyor's battery. Then they walked north to approach and photograph Block Crater. Bean was still carrying the HTC, which also held all the samples they had collected and had become quite heavy. After taking some rock samples from Block, Conrad returned to the LM to begin stowing items for departure. Bean followed, slowed by the heavy HTC. They worked at the MESA to store samples from the HTC in a rock box and an additional bag for return to Earth, trying to avoid getting tangled in the TV cable. During this process a bag containing a film magazine was placed on the LM footpad and accidentally left behind. It had not been used on the surface, but it had been used to photograph Earthrise from orbit before the landing.

Bean rolled up the Solar Wind Collector sheet and packed it. Then he used the Apollo Lunar Surface Close-up Camera (ALSCC) to take 15 stereoscopic image pairs in the vicinity of the LM. This part of the EVA was not documented with other images so the stereo image sites are not known precisely, but dark footprint tracks in LRO images show roughly where they were taken, generally to the north and northeast of the LM (Figures 157C, 160B). Some images were also taken close to the LM to record the effects of the descent engine exhaust. After the film was stowed safely, Bean threw the empty ALSCC to the west where it was visible in the post-EVA 2 window panorama. Its final location is shown on Figure 159. Then the two astronauts tried brushing excess dust off each other to reduce the amount tracked into the LM. Bean mounted the ladder and entered the cabin, and he and Conrad brought the rocks and Surveyor parts up to the cabin on the LEC cable. Finally Conrad entered the cabin, ending the second EVA, which had lasted 3 hours, 49 minutes.

The astronauts pressurized the cabin and prepared for departure. Items they no longer needed were stored in a jettison bag, including their boots and the remaining Hasselblad camera after its film had been used up taking images from the windows. Later the cabin was depressurized again so the bag and the PLSS backpacks could be jettisoned. The ALSEP seismometer observed the PLSS impacts. Those items can be seen in LRO images (Figure 157C). Gordon, orbiting overhead, had recently checked the crater Alphonsus after a report of a transient event, a

bright spot, west of the central peak. He saw nothing unusual from orbit. In the cramped and very dirty LM the crew ate and prepared for departure. While testing the attitude control thrusters the exhaust blew over the S-band antenna (Figure 157C). Finally, at 14:26 UT on 20 November the LM lifted off, ending a 31.5 hour stay on the lunar surface.

Figure 160B shows the second EVA route and activities, including panorama and sample locations. Sharp crater (Figure 160) was later renamed Sharp-Apollo to distinguish it from another Sharp crater on the Moon (45.7° N, 40.2° W). Figure 158 is a photomap of the LM area made by projecting EVA 1 panoramas onto an LRO image base.

Results of the Apollo 12 geology investigation include a measured age for the mare surface in this area of about 3.2 billion years, 500 million years younger than the Apollo 11 site (Papanastassiou and Wasserburg, 1971; Snape *et al.*, 2018). This conclusively demonstrated that all maria were not formed by the same event and that the Moon had had a fairly long and complex geological history. The regolith was estimated to be about half as deep as on the older mare sampled by Apollo 11. Some samples of possible Copernicus ejecta have ages of about 780-800 million years (Barra *et al.*, 2006).

Apollo 12 panoramas (Figure 159) reveal a diversity of craters. Figure 159A is a composite view to the west from both LM windows just after landing, with long shadows cast by the rising sun. Figure 159B is a similar view after EVA 2, showing deployed equipment and dark footprint tracks leading out towards the ALSEP. Figure 159C shows Bean's panorama of the landing site taken just north of the LM at the end of EVA 1, with Surveyor crater and some deployed equipment. The TV camera was set up to show activities near the LM, and was moved back to the LM just after this scene was photographed. Conrad is working at the LM. Figure 159D is a partial panorama across Middle Crescent crater, showing the astronauts' shadows and blocks on the rim of a small fresh crater. Figure 159E is a view of Surveyor Crater and the LM by Conrad early in EVA 1, with Bean near the LM. Figure 159F is a partial panorama of Sharp crater (later, and officially, called Sharp-Apollo) viewed from its eastern rim. The two astronaut shadows are visible, Conrad's in the middle, Bean's at far right. The rough rock-strewn interior is typical of very fresh impact craters. Figure 159G is a partial panorama of the Surveyor 3 site looking northwest, with the LM in the distance on the crater rim. Block crater is visible near the horizon. The shallow subdued topography of Surveyor Crater is typical of older lunar craters of this size (200 m diameter). Figure 159H is a view to the southwest across Block Crater and Surveyor Crater, with Bean's shadow and the LM just visible at right.

The Apollo 12 landing site was nearly 50° further west than Apollo 11's, so orbital photography (Figure 161) extended into areas not seen by earlier Apollo missions (Figures 130, 135, 147). Bootstrap photography of Fra Mauro helped confirm that area as the Apollo 13 target. After leaving lunar orbit on the return journey, lower resolution images were obtained from high altitudes. A white outline indicates a strip of experimental multispectral imaging, intended to reveal compositional variations. One magazine of orbital photographs including Earthrise images was inadvertently left on the lunar surface.

The Lunar Module ascent stage was separated from the CSM after unloading and deliberately crashed near the landing site to create a seismic signal of known strength for the Passive Seismic Experiment. The deorbit burn was two seconds longer than intended, causing the ascent stage to crash short of its target which was at 3.338° S, 23.411° W, 9 km south of the landing site. That location was announced by Apollo Mission Control shortly before impact, as reported in the Apollo 12 Flight Journal (https://history.nasa.gov/afj/ap12fj/15day6_ftstd.html). This had changed from the target given in the pre-flight Apollo 12 Final Flight Plan, which was 3.17° S, 23.23° W. Both sites are shown in Figure 166A. The later target, southwest of the first one, was probably intended to lessen the chance of an accidental crash at the landing site.

The ascent stage struck the surface 60 km east of the target, and despite the distance a prolonged vibration was detected by the seismometer. The impact location was estimated to be 3.920° S, 21.172° W, close to a hill called Fra Mauro λ (lambda) in the U.S. Air Force Lunar Astronautical Chart of the area.

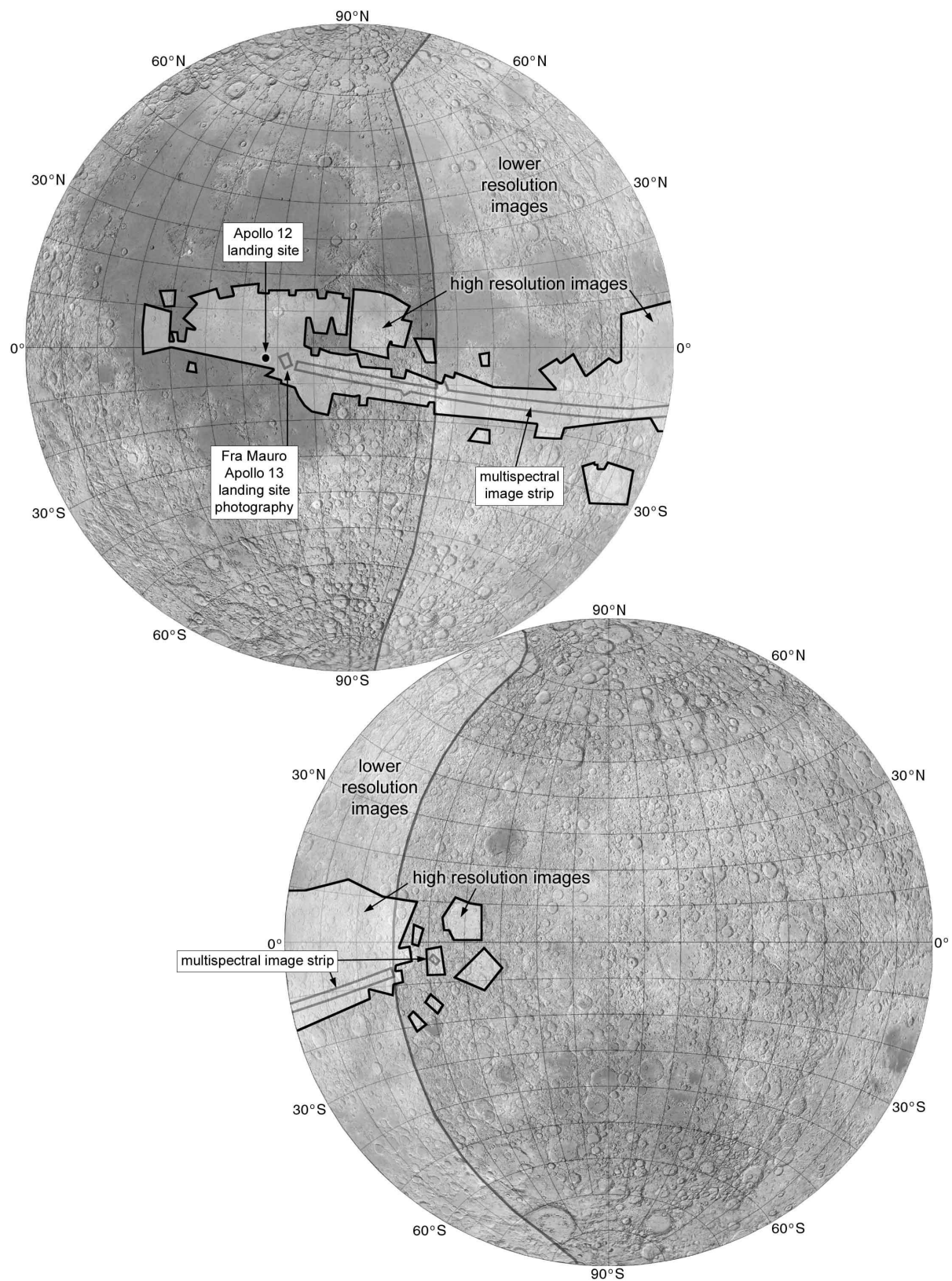


Figure 165. Apollo 12 orbital photographic coverage.

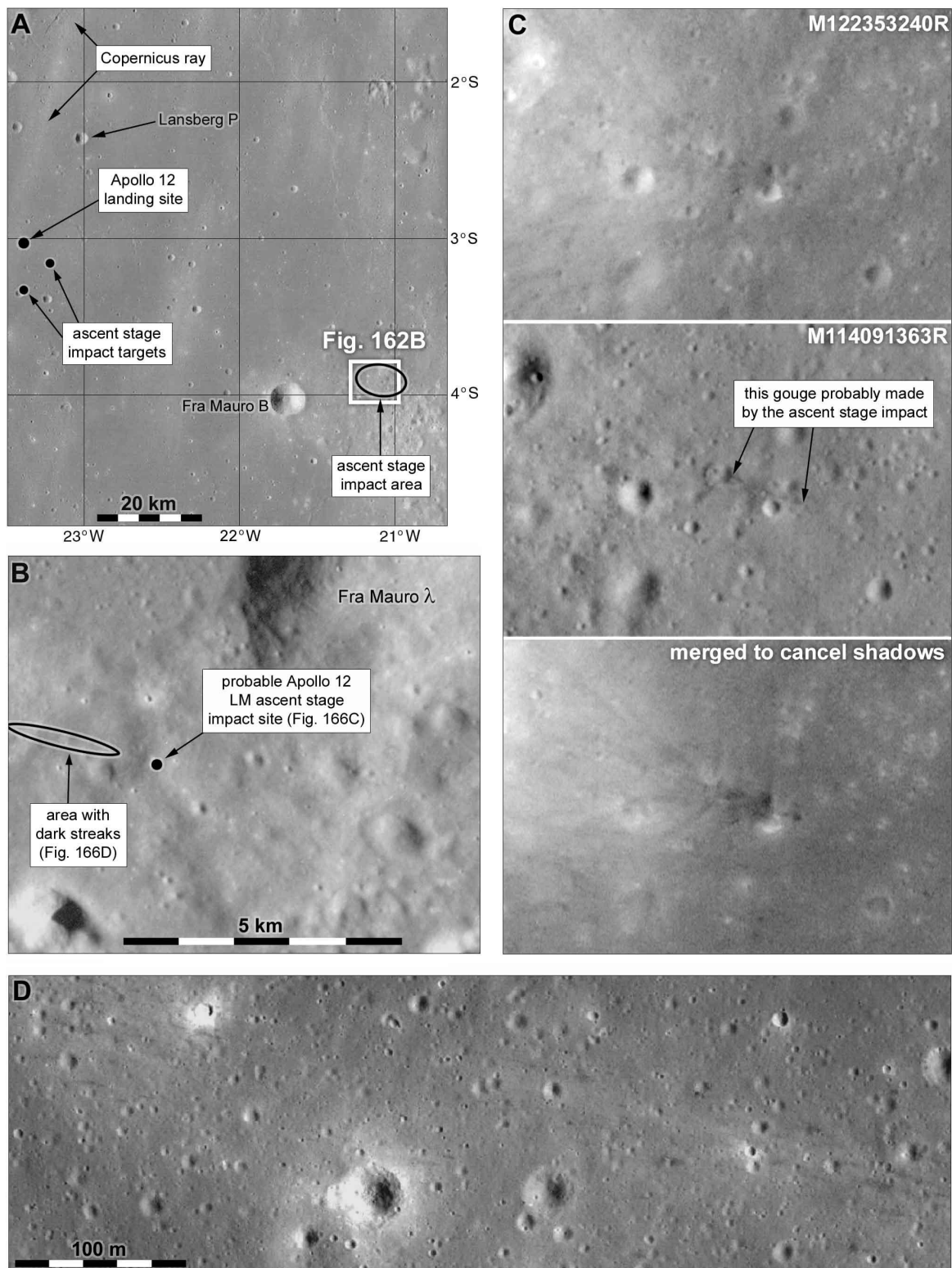


Figure 166. Apollo 12 LM ascent stage impact area. A: context map with LM targets and expected impact ellipse (LROC Wide Angle mosaic). B: part of Apollo 14 image AS14-73-10119 showing most of the impact ellipse. C: images of the probable ascent stage impact site. D: cluster of dark streaks, probably caused by impacts of fragments of the ascent stage.

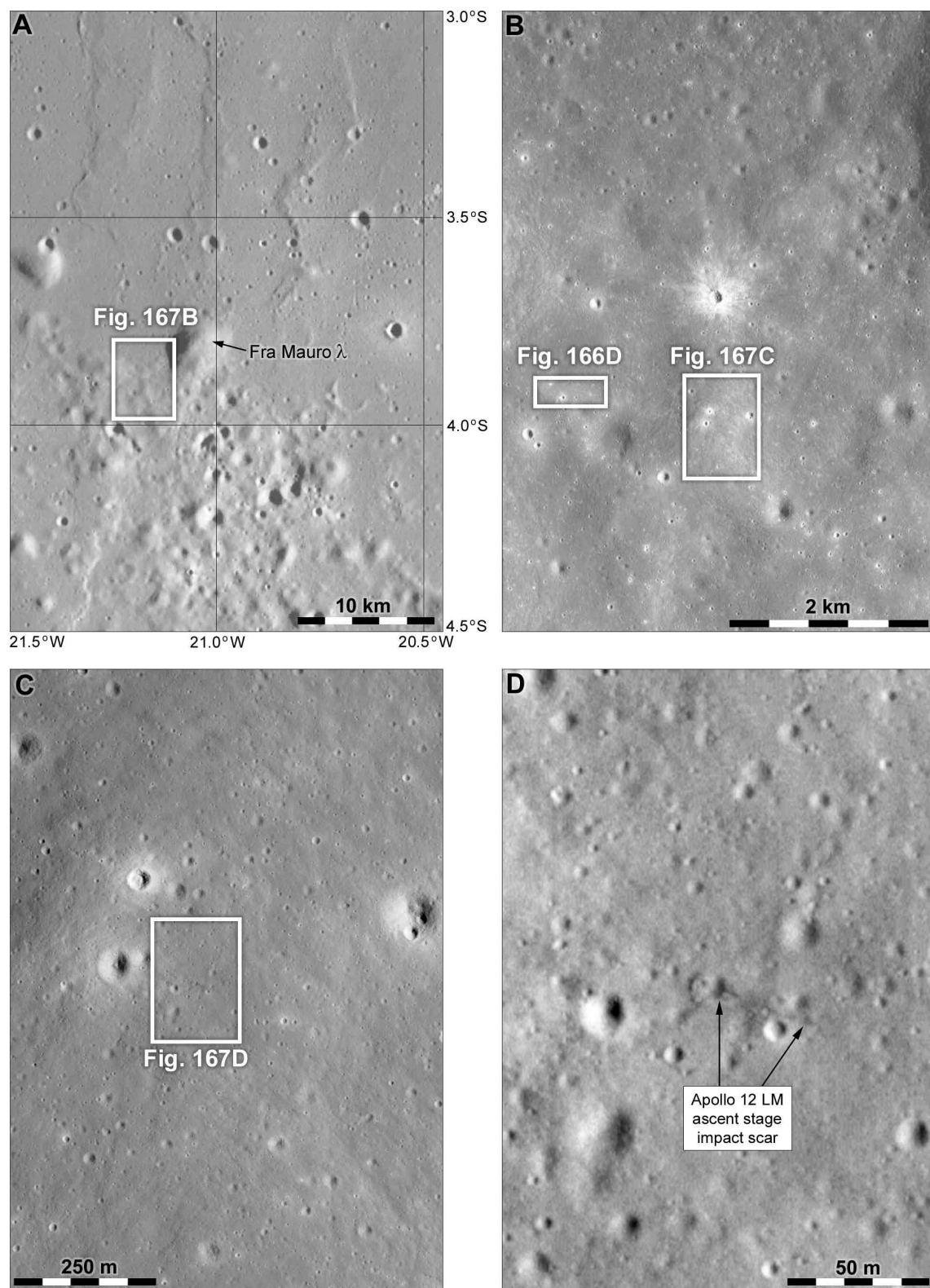


Figure 167. Apollo 12 LM ascent stage impact site. A is an LRO Wide Angle mosaic. B-D are from LRO image M114091363R.

Figure 166A shows the landing site region with target and impact areas, based on Figure 3 of the Apollo 12 Post Launch Mission Operation Report, but ignoring a locational error in that illustration and using the target coordinates already stated. The Copernicus ray which contributed to the selection of the landing site is indicated. Figure 166B shows the area of the impact ellipse in an Apollo 14 image. Given the uncertainties the ascent stage impact could have occurred anywhere in Figure 166B.

A band of small dark streaks can be seen in LRO NAC images, outlined in Figure 166B and enlarged in Figure 166D. This feature appears to be unique on the lunar surface and seems likely to be related to the impact site. The small dark streaks are roughly parallel, forming a band elongated in the direction of travel of the LM ascent stage. They may have formed as fragments of the disintegrating structure rained down on the surface. Figure 166C shows a linear gouge east of the band of dark streaks which is itself associated with a fan of light and dark markings and is clearly the impact site (Stooke, 2017; Stooke and Marcus. 2019). Figure 167 locates this feature in a series of nested images. The gap between this gouge and the band of dark streaks is a shallow depression, probably overflowed by the cloud of fragments after the impact. Similar streaks are not observed at any other spacecraft impact site, suggesting a unique but unknown circumstance associated with this impact, such as a catastrophic rotation induced by an initial grazing contact with the surface.

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Table A1. Spacecraft locations on the Moon, from this volume.			
Spacecraft	Date of contact	Location	Event
Apollo 11	20 July 1969	0.674° N, 23.473° E	Landing
Luna 15	21 July 1969	17° N, 60° E	Impact
Apollo 12 - LM ascent stage	19 November 1969	3.013° S, 23.422° W	Landing
	20 November 1969	3.920° S, 21.172° W	Impact

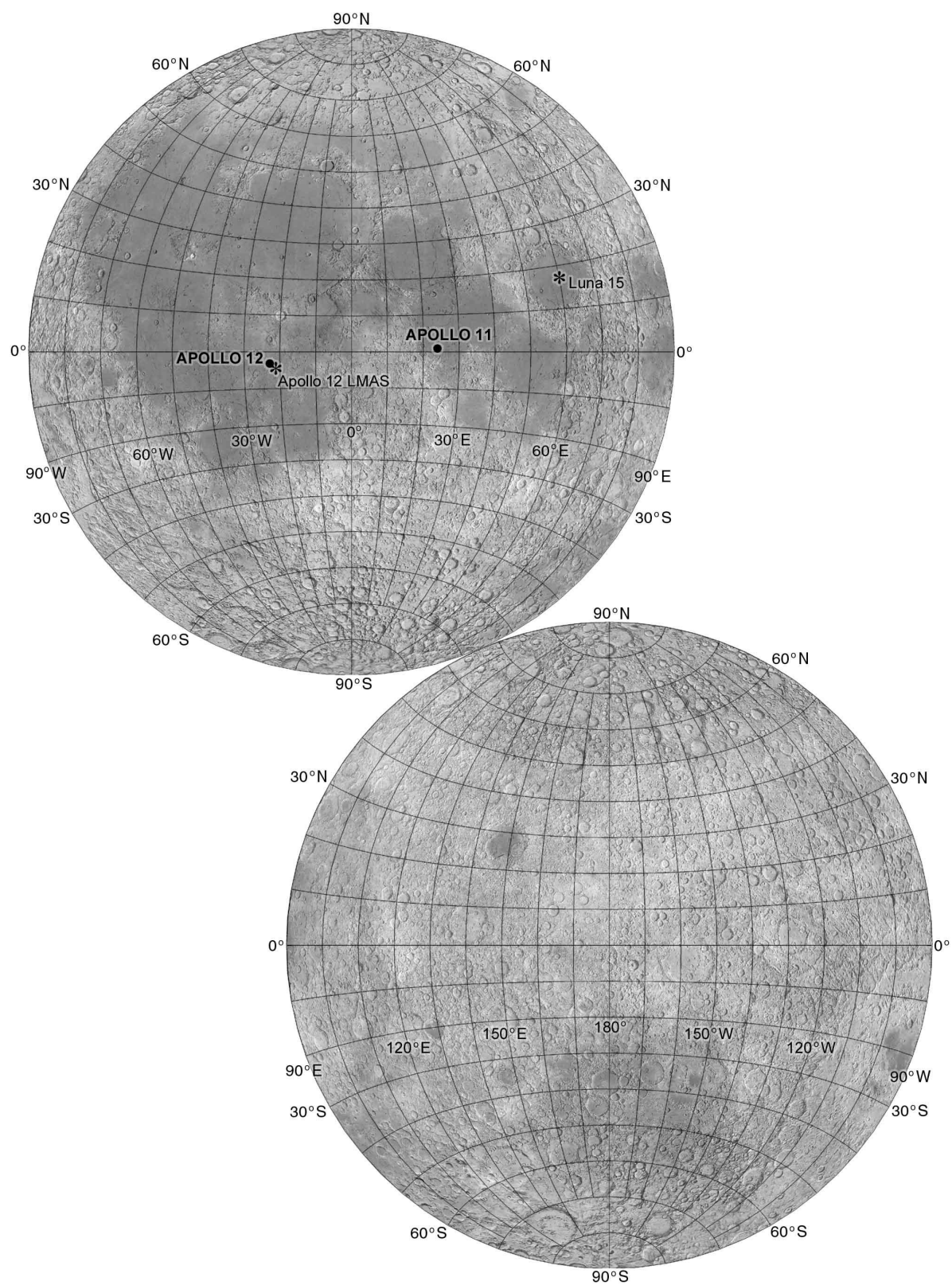


Figure A1. Lunar landings and impacts covered in this volume.